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University of Durham Philosophical Society

FORECAST AND FACT,

AS SEEN BY AN ASTRONOMER.

By R. A. Sampson, D.Sc., LL.D., F.R.S.

An astronomer is one who is interested in astronomy on the technical side. This separates him from the intelligent layman who is interested only in the prepared outcome of his work.

The technical side of astronomy is not widely known, nor generally attractive, and I have no intention of expounding it to you. I am in the position of an astronomer addressing an audience of intelligent laymen, and I must avoid technicalities, even where they are inviting. But I would not exclude them wholly from mention, because it is a necessary part of my thesis that the astronomer is limited by his own interests, as are equally but differently the physicist, the geologist, the students of living things, the physician, the merchant, the engineer, and the occupant of every other calling whether practical or learned; because he has only one life, and has devoted a large part of that, with absorption, to a special pursuit, which cannot be understood without absorption. When he turns to some other pursuit, he finds that his mind has been cut in grooves by his major pursuit, his nature is subdued to what it works in, and he is obliged to translate what is said into his own language, before he can understand it.

The limitations that are imposed by what a man has learnt to do are far more than negative. As I see it, the surge of life is like a crowd surging for an outlet and constantly feeling the pressure of new-comers behind it. Under such circumstances, it *must* do what it *can* do. The only things it *can* do are what it has learnt to do. These define the new world into which it is possible to expand. There is no reason to think them complete, and in fact they are far from complete. Hence we see the actual world defined, more and more closely, not by what is desirable but by what is workable.

If these are the circumstances of action, one would not expect, in a detached way, that the action would be right. Of course, it cannot be wholly wrong, for it is exposed to continual comparison with nature, and so subject to adjustment where nature conflicts with it. But that does not give any assurance that it represents more than some partial view, which may be blind to one side of nature, and which disregards methods of treatment that are above its capacity to handle. There is ample reason to think that this has happened. Certainly man is ever more and more actively transforming the world. But he transforms it, where he touches it, in order to suit himself. He need not feel any compunction in recognizing that he thinks only in terms of himself and his own interests. All that I ask is that you should admit that he does. Other creatures do the like, and with less disguise. A swarm of locusts turns kindly nature into a desert, wherever it passes, by devouring every bud and blade and blossom. Yet one would hardly say that they transformed the world, for they proceed without foresight, and their energy immediately defeats itself by ensuring their own starvation. Whether man does much the same, only at longer intervals, and is liable to get the contrivances, on which he depends, into an unworkable position, this is not the time to inquire. But at any rate, he is different. The tool by means of which he transforms the world, is his intellect. Before his intellect asserted its predominance, he would take, as far as we can see, a rather puny station among the beasts; the possession of an intellect has changed all that. Yet why should he think an intellect opens to him an universal scope? It is an hypothesis. It would never occur to one who watched with any care the reactions of others to his words. Rather we might quote:

> . . . in this sea of life enisled
> We mortal millions live alone.

It seems to isolate him. even from his fellows, and even more than one might expect. I want you to recognize that an intellect carries with it no guarantee of completeness, but has transformed and also circumscribed man as well as his world.

I hope no one will be apprehensive that I am going to steer out into the wide ocean of human history. The point I wish to make may be summed up briefly : progress is like a spring, welling up and covering the land; it searches out everything it can reach; but the ground it works on is uneven, and so it advances far more in one direction than another, and may leave some parts quite untouched.

I would work round to the same view from another point. I see in what is successful and workable always a cumulative aspect. Man has become rich, not because he wished to benefit posterity, or because he has ever aimed at more than an immediate advantage over his fellows, but mainly because he makes things he cannot consume. William Rufus is a name of which I know no good, and he certainly never planned for us, but he built Westminster Hall, and it remains for our use. Yet infinitely richer are we for what is written and learnt, and which equally cannot be taken away. Westminster Hall might perish, though it has lasted eight hundred years; but we cannot imagine the principle of the dynamo becoming again unknown, though it is only one hundred years since it was discovered. More than that—Chronos eats his own children, and some day Westminster Hall *will* perish; but every year that passes roots the great discovery of Faraday more firmly in our life, and its own ramifications support it. Every civilized nation uses it. It and its kind make communications easier, and because communications are easier, all the world can and does join in improving it and its kind. And so the tale of science goes on, taking something from us but giving us much more, filling up our life and shaping it.

Shaping it. There's the rub.

The process by which shaping goes on is, simply, selection. We select what we can do, and that means, what is easy to understand. We select what gives us pleasure. Such things are thrown into artificial prominence by selection. For example, nature offers us stone in abundance, but hardly ever a stone that presents any regularity. There is no reason why a stone should be of one shape rather than another, but by hewing it and splitting it, any stone can be made square and subject to an intelligible plan of building. So we square it and we build with it, and thus and similarly arise all the delights of architecture. In the same way, the metals we use—iron, copper, aluminium—are offered freely but in forms we cannot employ until we have simplified them. Most of us thereupon forget the natural form and think only in terms of the simplified shape. These are obvious instances, but on brief reflection you will see that we exercise selection upon the whole mass of nature, and in addition, on the accumulations we have already selected and simplified. The latter part is easier to operate upon, because it has been already prepared, and hence is seen an unceasing and quickening process towards a more and more artificial world, as though we were set upon building ourselves into a cage or chamber, from which we have mostly no desire to escape, and could not, if we had. In short, by selection, the world grows more and more scientific, with effects which now and henceforward, no one can ignore; and while it grows more and more scientific, I think it grows more and more one-sided.

I am no champion of the noble savage. It is quite possible that to dwell inside this chamber is more agreeable than to dwell outside; for example, that what Montaigne delightfully calls "the habit of wearing clothes" is a good habit, as is that of washing. Many people get their chief pleasure from the frills and furbelows of life. We may reflect that, if we cannot run like a horse, we can mount the horse, if we want, and can teach him to run better than he ever could have run without our aid. Admitting for the sake of argument that our procedure entails a certain limitation, we might be content to forego the loss, and mostly are content to forgo it, but for one condition. We cannot rise superior to nature. Nature is the source of all energy and action. Nature brings us into the world and takes us out again, and does not ask our consent for the one step or the other. Nature occasionally over-rides our plans wholesale. Nature appears to be indifferent to what man does, as though his disturbances of her course were too slight and temporary to be worth attention, or rather as though, man being here, he were a member of her family also, and might be left to find his own place.

Man boasts that he has transformed the dog and the horse, and made rubber trees grow in Malaya, and bananas in the West Indies, and united the Pacific and Atlantic oceans by a channel, but that is nothing to the species Nature has negligently produced and as negligently destroyed, or the changes of plant life or rock form she has seen occur. Nature is in no hurry, and will accept without protest whatever happens. She has no objection to effacing her own past, as she has done in the civilizations that have been produced and then destroyed. Man is by no means her only care. All the time that man is raging on the surface of the earth, his eye fixed anxiously on his chief remaining enemy, his brother man, an innumerable multitude of fishes populate three-quarters of the globe, and an equally innumerable host of insects other great tracts. Besides this, in a way that seems to us curious, the same ground is used two or three times over, for worms and parasites and microbes. These have no intellect or feeling, as we suppose, but they are subject to the laws of Nature and her development, as we are, and are nearer to her in many respects than ourselves.

These things have often been said, and, important as they are, I should not have brought them again before you, except to introduce a sense of proportion into the discussion, to emphasize the need of liberating ourselves from anthropomorphic bias, if we aim at broad and true views, and in particular as a warning of the artificial ground we are on, if we attempt any speculation, and a reminder of the partial character of any view we are likely to form if we build upon science.

I shall not take a multitude of instances of this. One or two will suffice.

It will not have escaped your attention that we have heard a great deal recently about the universe. That would be very nice, provided we can rely upon it. So long as I can remember, people have wanted to know what the universe was. You will not expect me to tell you what the universe is; it is far too big a subject for me to handle, but the same restriction does not apply to some descriptions of the universe, which have been prepared for busy people and immediate assimilation. By reading these accounts one might suppose that we had really got to the bottom of the matter at last. The mathematician—the *ne plus ultra* of certainty—is cited as certifying it. But I wonder whether we have. I am domiciled in a cautious country, where a common reply to a proposition is the phrase " I hae ma doots."

What makes me pause is this : One feature of nature, as it is presented to us, and apart from what we have thrown into prominence by selection, which comprises almost all that we live in, is that it is hard to describe. It is full of differences, but the separations are never well defined, at least on the macroscopic scale. They are repeated, they flow into one another, they change gradually into something else. All around us in this Hall is artificial —perpendicular walls, dressed wood, colours and clothes. To find nature unchanged by man, think of some mountain track, where one tries in vain to follow directions that seemed so clear before one started. Even when taken scientifically, nature is complicated, *instar labyrinthi,* a veritable labyrinth, as Bacon called it. Yet physicists tell us that on the microscopic scale, or rather, far beyond the microscope or anything else we can see, nature is utterly different, precise, defined, enumerable in less than a hundred elements, and these made of two kinds of stuff only; and that it follows rules—the quantum conditions— which produce all sorts of consequences that have no parallel in the coarse-grained world we usually reckon on. One may suspect that the physicists have overdone the simplification, having of necessity to state a system they can argue about, and furnished with no guides but their own prepared experiments and their own logical apparatus. Still, far be it from me to say they are not right. On the contrary, I think that there can be no question that the view contains a remarkable degree of truth. I should be ready on a suitable occasion to claim your admiration for the intellectual feat which has penetrated so far into dark and undreamed-of places, where our coarse-grained sense-impressions forbid an entry. But it is not being a sceptic to say that we do not yet know everything, even of what peoples this artificial and simplified world. There may still be upheavals upsetting this upheaval. And I will tell you why I think so—I cannot make the accounts square with one another.

Let us take one of the simplest, widest, and most generally accepted conclusions. It originated in the time of our grandfathers, but it is still current—I mean the "heat-death" predicted for the universe. Of all forecasts it is the one the average man would most willingly do without, and of all forecasts it seems the most certain.

If you take a pack of cards fresh from the maker, says Eddington, you will find that it is ordered in suits. Shuffle it, and you never get back to that favoured position. Mere chance exchanges of order lead you farther and ever farther away, from what may be described as privilege, towards uniformity, or rather, towards complete muddle, from which you never extricate it. In the same way, the end-position of moving bodies, left to themselves, however you start them, is one of average equipartition of energy; the end-position of the particles of a gas is one of average uniform pressure, and the end-position of the universe is one in which everything is as cold as everything else. Place a kettle on the fire, says Jeans, and it *might* freeze. But according to our experience it is not likely to. The reason is the same. There are more ways—more numerous beyond all computation—by which heat can pass from the fire to the kettle than from the kettle to the fire; just as the original arrangement of the pack of cards was unique, but the arrangements you call "shuffled" are multitudinous. Of course, any one of them is unique also, like the original arrangement in suits, and is equally unlikely to recur; it is only that we are not interested to distinguish them that makes them a multitude.

These instances have been made striking by the authors in order to catch your attention, but any instance will do. To make the matter clearer, take a less picturesquely provocative instance. Imagine an iron bar heated at one end. The heat will diffuse along its length, and ultimately it will be of the same temperature all over. While one end is hot and the other is cold, the tendency towards equal diffusion may even be used to produce mechanical work, as engineers know well. Engineers use systems more favourable to their own practical purposes, but the principle is the same. When the temperature is the same all over, obviously nothing more can be done. There is what is called a "heat-death." This heat-death has been taught very widely as the destiny of all things—the earth, the solar system, the universe itself. The word "death" may be inappropriate, because it evokes ideas that have nothing to do with the case; but let the authors of the name answer that. We need not quarrel with the name if we cannot escape the malady. The prospect suggests a dismal and chilly picture of lifeless remains of our universe, circulating for ever, without that play of change that gives it interest. Of course, long before that time arrived, we should have ceased to take any interest in it, so that the picture is gratuitous, serving only to make our flesh creep. We might dispose of it by saying, "It's a long time off; let's hope it isn't true," as the ignorant old woman disposed of the story of the Crucifixion. Scientifically, it is only of value if it is a certainty. But *is it*?

Matter, on the microscopic view—I shall use the word "microscopic" to designate the description in terms of atoms or electrons, though this is far beyond what can be seen with the microscope—is regarded as a tangle, rather like a piece of felt, where the separate fibres have nothing to hold them together, and yet do not part because they impede one another. Cordage is only a more scientific tangle, and you can make it as strong as you like. From this point of view, the iron bar is just a tangle of certain complicated atoms, each built up of electrical constituents, according to a plan that is clearly, if imperfectly, seen. When one end of the bar is heated, one must think of the atoms at that end as thrown into irregular, local agitation, which agitation gradually spreads itself throughout the whole bar. Hence the spreading, and consequently the heat-death, is wholly dependent upon the agitated atom being unable to separate itself from its neighbours, and being forced therefore to share its agitation with them. It is dependent upon a certain constraint. Every form of heat-engine that we can imagine involves such a constraint. To illustrate what I mean, let an engineer set to himself the problem of devising an engine without walls to its boiler, and confess that it is beyond him. The same is true of any instance you may consider. Even the pack of cards that is shuffled is supposed to keep together.

But in the simplified, microscopic view, there would be no constraint, because matter, as we know it, would not occur. If, somehow, you conferred energy upon an atom, it would get away with it, and the ominous Second Law of Thermodynamics, of which we have been speaking, and which predicts the degradation of all energy and a heat-death for the universe, would not apply.

Physicists, I may say, know this quite well. But they are in the habit of discussing questions in sound-proof rooms, each marked upon the door with a large and different IF. Occasionally, to astonish you, a specimen is brought from one room to another, though, if that is done, it is liable to get lost, since there is no place to put it. Thus Eddington, whom I have also quoted as the sponsor of the Second Law, and who might be quoted with reference to several points of view, recently showed that the temperature of outer space should be called 10,000° C., which seems not less astonishing than if the fire should freeze the kettle. The difference is simply in the IF. If matter is fundamental, as our grandfathers supposed, there is degradation of energy, resulting in a heat-death. If there is selective absorption, each atom takes what suits it.

If the law of degradation of energy does not apply without reserves, it is a very serious matter to those who make a trade of heat-deaths, and it is only reasonable to ask whether there is not enough truth in their dogma to serve all purposes that matter to us. It is true that matter may, from a general point of view, be a mere complication of what is best studied in the simpler form of electricity, which in all conscience is difficult enough; and the matter that we can handle may be already essentially dead and limited. But we, also, are limited, and physically we are conditioned by matter. Anything physical that matters to us is composed of matter. We have not to look far for a world which we have good reason to believe to be dead, namely our nearest neighbour, the moon. It is possible that some changes go on, even in its surface. Some, who have studied the moon intensively, believe that they do. But if so, they are slight, and the moon may be taken as pointing the way to the destiny of the earth. The forms of matter into which it has congealed, and which we have no reason to believe to be different to those on the earth, would seem destined to remain for ever unchanged, circulating round the earth, gradually receding from it, so long as the latter offered any tides in its body or on its surface, but in all that matters to us, dead enough to satisfy the most critical. But again, is that the case? How about cosmic rays? Cosmic rays were unknown a few years ago, and they are half known still. But it is already certain that the earth and all our system are bombarded by particles of extremely high velocity, even as ray velocities go, which come from outer space, in no favoured direction, continually and in great numbers. What they arise from is at present a matter of guess, but what their effect will be can hardly be in doubt. Everything exposed to them will gradually be shot to pieces. How long it will take is neither here nor there; there is no hurry. When the surface is disintegrated, the lower layers will be exposed and will suffer the same fate. Hence the microscopic view does not point to a dead world circulating for ever in meaningless motion, but one in which every particle of matter has been renewed, transformed and removed. What happens then? I suppose that then the story begins again somewhere else.

These are such obvious and inevitable considerations that I feel bound to assure you that I am not trifling with you, and propounding paradoxes that an ingenious man, on a moment's reflection, could demolish. I think seriously that these great prophecies fall down like a house of cards when you puff upon it; and yet they are fairly representative of what you get under the name of "mathematical certainty." My contention is that in respect to remote epochs, and especially remote epochs in the future, we know next to nothing; and the material for forecast, which must be sharply defined in order to carry to a distance, is very unsuited to describe anything we know. It may be compared to a shot fired without being sure of one's target. The proceeding may be very impressive at our end, and the gun may go off with a roar and recoil, but it is most unlikely that it will hit anything that matters.

Then, finally, what is the proper attitude for us to take, as serious men and women, who are very much attached to this world with all its faults, and who have to carry it on, for a brief period, as well as we can? I think we ought to distinguish between the immediate applications of science and the wider claims that are sometimes made for it. Science is a very artificial product, we must remember. It must always be taken with the admixture of a grain of salt —the salt of common sense. For immediate uses science is absolutely indispensable. It is more indispensable than the wheel and the knife which it has created. Or, not talking as if we were in a museum, and passing away from prehistory where these inventions belong, how, without science, would insulin have been made? How, without it, would broadcasting have been found, or flying, or X-rays? The instances could easily be multiplied a hundredfold. And costly as some of its experiments may be, and yielding no visible return, it is infinitely more costly to follow any course inferior to the best, as anyone finds out immediately who is undercut by an improved method or a new discovery. This is the practical side. Further, an intelligent man readily grasps that science must be cultivated in its own soil and on such terms as it can thrive by, little as these may seem to him to comport with system or efficiency. Even our public, which is not remarkably favourable to theory or to long views, may be said to have grasped that fact. But on the practical side, practical results must be forthcoming. If a man says he can cure cancer or anthrax, or if he claims to be able to transform mercury into gold, be sure that he will be asked to do it, and must stand or fall by the result.

Compared to these practical uses, the long shots of science seem to be separated by a whole world. I say "seem to be separated" because those who know science from the inside are well aware that all that is really momentous in practical results, that is to say, what is really new, is due to minds, like Faraday's, that do not care one fig for practical results; and that the theoretical absorption of a mind like Einstein's, in the midst of a practical world, produces its effect in a turning of the soil, a revolution of ideas that sets the whole world on the alert for something new. From this point of view, we regard the theoretical mind as the soul of science, which must be there or the thing is dead, but which is too shadowy to define. It is

> the prophetic soul
> Of the wide world, dreaming of things to come,

and it changes the thread of its dream without effort or reluctance. Vaguely and half comprehended it projects itself upon a necessarily practical world; and vaguely, too, and lightly it holds what it sees. Most of us dream sometimes, and some of us wish to tell dreams in words. But only a poet like Blake can do it, for a dream hardly stands telling and words congeal it.

> To a lovely mirtle bound,
> Blossoms show'ring all around,
> O how sick and weary I
> Underneath my mirtle lie!
> Why should I be bound to thee,
> O my lovely mirtle tree?

What does that mean? Is it sense? Is it nonsense? Why ask? Or

> Around, around flew each sweet sound,
> Then darted to the Sun . . .

Pure nonsense, is it not, if physical science is sense? But again, why ask if it is sense or nonsense? What he has to say, he says, and it transcends sense.

Therefore when you read any forecast of science, you should read it as you read an imaginative poem; as you read Blake, or "The Rime of the Ancient Mariner," or "Kubla Khan," breathing its air, walking in its stride, and not for one moment trying to trap it by a cross-question into a contradiction, lest it should vanish from sight, and leave in your hands only its husk.

SOME ASPECTS OF THE THEORY OF STELLAR STRUCTURE.

By Prof. E. A. Milne, F.R.S.

[Lecture delivered before the Newcastle Astronomical Society, March 4th, 1932.]

Abstract.

There are in principle three " observables " connected with a star—its mass M, its luminosity L and its effective temperature T_e. From the luminosity and effective temperature the radius r_1 may be inferred, and it is found to be simplest to confine attention to the three descriptive variables L, M, r_1. When a star is in a steady state, it must be generating in its interior, per second, an amount of energy equal to that radiated at its surface. We thus infer that the star is furnished in its interior with sources of energy totalling to L.

The practical problem is, what is the relation between the three variables r_1, M, L? In other words what is the radius of a star when its mass is known to be M and its luminosity known to be L? Nature's answer to the problem may be summed up in the " Russell diagram," in which luminosities are plotted against effective temperatures, and curves of constant mass superposed. More insight is, however, gained by plotting against L/M not T_e but the radius r_1. The observed stars are then found to be distributed close to the loci roughly (and only qualitatively) sketched in the following diagram.

In this diagram gM denotes the giant red stars of spectral type M; dM the dwarf M stars of the same spectral type M; W.D. the white dwarfs; P the nuclei of the planetary nebulæ; A the stars of spectral type A; B,O the stars of spectral types B,O; and the dotted line indicates Cepheid variables. The diagram is somewhat idealized, and in parts conjectural, but it brings out several features worthy of comment.

In the first place the absence of red stars of intermediate values of L/M—the famous gap between giants and dwarfs—is no longer mysterious. Such stars, if they existed, would be far away from the loci defining the "main sequence" dM—A—B—O and from the giant sequence A—gM. In the second place, for the larger values of L/M we find two distinct types of configuration, the giant red stars, of very large radius, and the B,O—stars of smaller radius. This has hitherto escaped much attention. But it is a simple matter to verify it, for we can usually pick out, from lists of typical stars, for any given large M and the corresponding large L, two stars, one of type M (giant) and one of type B or O, the one of much bigger radius than the other. In between we find the Cepheid variables. It follows that any adequate theory of stellar structure must predict the existence of two different types of configuration for given M (sufficiently large) and some corresponding L lying within the observed range of the mass-luminosity correlation.

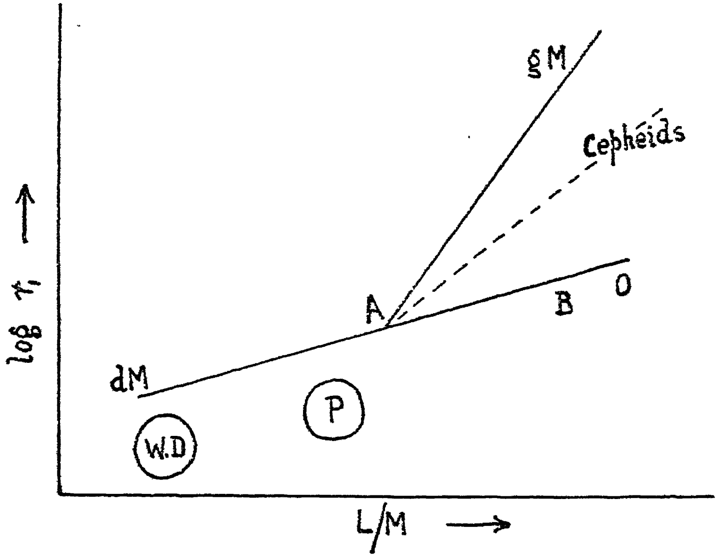

FIG. 1.

Theoretically, the problem " What is the radius or radii for assigned L and M ? " cannot be answered outright, for we know nothing in the first instance of the internal state of aggregation of the matter composing the stars. Instead, we have to re-formulate the problem thus :

A star is observed to possess mass M and luminosity L. What are the possible steady-state configurations (and in particular what are the radii) of aggregates of matter of mass M when endowed with sources of energy totalling to L?

If we can construct mathematically all such possible steady-state aggregates, and determine their radii, then we can identify that one of the aggregates which coincides with the observed star by comparison of radii. For the observed radius is the only additional variable at our disposal which can disclose anything of the internal state.

Amongst the possible steady-state aggregates we can enumerate (1) the "one-phase" (purely gaseous) configurations, (2) the "two-phase" (gas/degenerate gas) configurations, (3) the "three-phase" (gas/degenerate gas/relativistically degenerate gas) configurations, etc. Before the discovery of the high density of white dwarf stars, only gaseous configurations were contemplated. But the philosophic importance of white dwarf stars lies in the circumstance that they demonstrate the possibility of the assumption by matter of a very dense, so-called "degenerate" phase.

It is well known that one-phase gaseous configurations do not yield radii agreeing in absolute amount or in relative groupings with those of the observed stars. By the investigations of Jeans, Eddington and Russell, a prescribed pair (L, M) has a unique radius r_1 given by

$$r_1 = \frac{\text{constant}}{(\alpha \text{ L})^2} f\,(\text{M})$$

where α is the coefficient in the law assumed for the opacity, $\kappa = \alpha\rho/\text{T}^{7/2}$. The uniqueness of the predicted radius is in conflict with the simultaneous existence of the two groups, gM stars and B,O stars. And when the

theoretical value of α is substituted in the formula, the calculated value[1] of r_1 comes out about a hundred times larger than the observed radius r_1 for any observed pair (M,L) selected from amongst the "ordinary" or "non-dense" stars.

The inference is immediate that the stars are more strongly condensed to their centres than gaseous configurations, and thus probably comprise a strongly condensed core embedded in a gaseous envelope. I have recently re-examined (*Zeits. für Astrophys.*, Bd. 4, S. 75, 1932) the theory of gaseous configurations, and come upon substantial modifications in the formula for the radius r_1 when boundary conditions are properly taken into account. But the radii thus indicated for purely gaseous configurations are even larger than before. It is probable that the stars were only gaseous at the time of their first formation by separation from the primeval nebula, at which epoch they would be gas-spheres in contact with one another. They must then have condensed, ultimately to their present small radii. Thus the present observed radii of the stars indicate that they cannot be gaseous throughout.

We therefore turn to two-phase configurations consisting of a degenerate core surrounded by a gaseous envelope. The full theory of such configurations, with the laws of opacity appropriate to the gaseous and degenerate zones, is very complicated, and not much progress has yet been made with the calculation of their radii. But when we simplify the problem by adopting constant (but different) opacities in the envelope and core, and adopt too the false-to-nature but convenient boundary conditions, $\rho=0$, $T=0$, it is possible to carry through the analysis in detail. Though the resulting external radii are smaller than those of the observed stars, the *relative* radii as functions of L/M and M agree in many cases with the groupings of the observed stars, and it is probable that this model (the "generalized standard model") gives great insight into several of the features of the Russell diagram.

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[1] I am indebted to Mr. T. G. Cowling for drawing my attention to this point.

The simplest parameter descriptive of these two-phase configurations, for prescribed L and M, is the ratio of the radius of the core to the external radius of the configuration. The figure shows this ratio plotted against a variable proportional to L/M, for constant M, as found by detailed calculations. The curves do not depend upon any adjustable constant.[2]

In calculating these curves the opacity κ_2 of the degenerate core has been taken as negligibly small compared with the opacity κ_1 of the gaseous envelope, in accordance with recent investigations by various workers. The core is, in fact, an approximately isothermal mass, maintained at its temperature by the opacity of the gaseous envelope, which acts as a blanket. Relatively small cores have relatively high temperatures, of the order of 10^{10} degrees; relatively large cores, like the cores of white dwarf stars, have relatively low temperatures, of the order of 10^7 degrees. The small cores, when associated with high values of L and M, may possess very high temperatures indeed, and we see that the configurations with the highest generation of energy (largest L/M) have the hottest cores.

In the diagram the external radii of the spheres occupied by the complete configurations are represented *qualitatively* by circles. Open circles correspond to "centrally-condensed" configurations, shaded circles to "collapsed" configurations. They are separated by the locus YA, which gives the "quasi-diffuse" configurations.[3]

A typical mass curve such as that for $M = 20\odot$ (*if* $M > 2{\cdot}6\ \odot$) proceeds from E, where $L/M = 0$, $a/\xi_0 = 1$[4] (completely degenerate configuration) to the locus AY which it intersects at S^1. It then bends round and down and meets the locus $a/\xi_0 = 0$ at a point T^1 vertically below

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[2] In order to *label* the curves we require to introduce a value for μ, the mean molecular weight in the gas-phase. The shapes of the curves do not depend upon μ.

[3] "Quasi-diffuse" configurations have a gaseous envelope of the same density-distribution as the outer layers of a wholly diffuse configuration.

[4] "a" is the radius of the core on a certain scale, ξ_0 the external radius of the configuration on the same scale.

S^1. Any ordinate not too far to the left of S^1T^1 meets the mass curve in two points S,T. Thus for any assigned value of L/M exceeding that corresponding to the point T^1 (but not much exceeding it), and for the assigned mass M, there are two distinct configurations possible, of two different relative core-radii and accordingly two different external radii. It is tempting to suppose that this phenomenon, for this special model, is the counterpart of the existence in nature of the two distinct gM and B,O configurations for large L/M. We at least gain some insight into the existence of the duplicity-phenomenon.

The next point to notice is the possibility of the existence of configurations represented by the points such as W, where the tangent is vertical. Such a configuration has the maximum possible value of L/M for the given mass; and for this configuration the value of a/ξ_0 is capable of infinitesimal alteration without the configuration ceasing to be a steady-state configuration. In other words, the core-radius is slightly indefinite; hence the external radius will be slightly indefinite. Hence pulsations will be apt to occur. Thus configurations represented by points such as W will tend to have some of the characteristics of Cepheid variables. We observe that the configurations likely to have a variable radius (*a*) have the maximum possible luminosity for their mass; (*b*) have a radius intermediate between the two configurations of two greater and less radius for the same mass and for a slightly smaller luminosity. These properties characterize the observed Cepheids of nature, for these are stars of high luminosity and are generally of spectral types F and G, i.e. of radius intermediate between the giant M stars and the O stars of similar mass.

When we pass to other laws of opacity the loci of Fig. 2 will probably be deformed, but will probably continue to possess the property of comprising an arc one point on which has a vertical tangent. Such a point will again correspond to configurations likely to possess Cepheid characteristics. I therefore definitely put forward the hypothesis that Cepheid variation is associated with the possession of a core-radius r^1 such that dr^1/dL for constant M is infinite. The oscillations about such a steady-state configuration will be quite unlike the ordinary pulsations of one-phase systems usually studied, and will involve the alternate condensation and "evaporation" of a layer of material on the core. Hitherto the difficulty has been that all stars ought to show pulsations or Cepheid characteristics. The new hypothesis selects a particular class of configurations as alone likely to yield natural changes of radius.

We proceed with other properties of the configurations enumerated in Fig. 2. The curve T^1TWSS^1E is a continuous one, embracing a linear series of configurations of steadily increasing core-radius. But a configuration of decreasing luminosity,[5] beginning at the point W, must pursue either the path WSS^1E or the path WTT^1. Along the path WSS^1E we have configurations of steadily increasing core-radius, and so steadily decreasing external radius, the luminosity L (or L/M) steadily decreasing to zero. Along the later part S^1E we shall have fairly dense configurations, possibly of quite large mass, but of low luminosity. These may well represent the nuclei of the planetary nebulæ of nature—stars of possibly large mass but relatively low luminosity. Along the other path WTT^1, the configuration increases in external radius. What happens as the representative point reaches T^1? If the luminosity L decreases below the value appropriate to T^1, the only way in which the system can find a configuration of equilibrium is to jump discontinuously from T^1 to S^1. The core-radius then increases cataclysmically, the external radius decreases cataclysmically, much gravitational potential energy is suddenly lost and a great evolution of energy must occur during the ensuing cataclysmic motion. The accompanying phenomena will resemble those of a Nova outburst. For after the outburst the external radius will be smaller than before, and the effective temperature thus much larger; the final luminosity will be closely the same as the initial; and the sudden liberation of energy will cause the expulsion of the atmospheric layers by the suddenly increased radiation pressure. When these outer layers have disappeared into space, a small star of high effective temperature will remain.

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[5] It is not suggested that an evolving star necessarily remains of constant mass. But the sequence of possible configurations is much the same if the representative point passes from curve to curve as the mass decreases.

Deformation of the curves, so as to represent other laws of opacity, will leave the existence of this discontinuity unaffected. Hence the Nova phenomenon may be expected to persist for other laws of opacity. I therefore definitely put forward this discontinuity as a possible explanation of Novæ, though the details may well be different when the opacity is not taken to be constant in the separate phase but varies with temperature T and density ρ.[6]

It will be remarked that towards the bottom left-hand corner of the diagram configurations exist of large M, large L/M and large external radius. This is the region of low effective temperatures, and so of giant red configurations. But it is precisely in this neighbourhood that curious kinks develop in the curves of constant mass—kinks which exhibit two points at which the core-radius possesses the property $dr^1/dL = O$ for constant M. These two points divide the loci of giant configurations into three arcs, and the corresponding configurations presumably possess different types of properties. Now it is precisely in the region of giant red stars that nature exhibits different types of configurations, namely giant M-stars, long-period variables, giant R,N-stars and giant S-stars; all stars of large M and large L/M, so far as is at present known. I cannot identify these various types of stars with the various arcs on a typical mass-curve near L and L/M large. But it is worthy of note that just where the special two-phase configurations of our theory behave in a somewhat unexpected way, we find also nature producing different types of actual stars.

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[6] The point T^1 will be defined in general as the intersection of a series of two-phase configurations with a series of one-phase configurations.

Apart from these kinks, the curves of constant mass, for $M > 2 \cdot 6 \odot$ below the curve YA, are fairly vertical. For $M < 2 \cdot 6 \odot$ the curves are also fairly vertical, but do not bend round. They possess no vertical tangent, and the Cepheid phenomenon does not occur. Thus we should not expect Cepheid variation to occur for $M < 2 \cdot 6 \odot$ on this model. Again, the nova phenomenon—the discontinuity—is no longer possible. There is simply a continuous series of configurations passing from zero core-radius to a core-radius comprising the whole configuration, as L decreases to zero. I suggest that the more luminous of these configurations may be identified with the ordinary dwarf stars of nature, the less luminous with the white dwarfs. Thus a configuration of not too large mass can reach the dense state continuously, whilst a configuration of larger mass can reach it either continuously or discontinuously.

The approximately vertical character of these curves of low mass, and of the curves of higher mass below YA, will yield an approximate correlation of L/M with M for the corresponding configurations. That is to say, for any assigned M, the permissible range of L/M and so of L, is for a considerable range of configurations very small. Values of L exceeding the upper limit of this range are incompatible with the existence of configurations; presumably for such values of L radiation-pressure is so large that equilibrium (for the corresponding mass) is impossible. Values of L less than the lower limit of the range give rise to dense configurations. I suggest this as the explanation of nature's mass-luminosity correlation; namely, that for the most part the permissible range of L for given M is very limited. The occurrence of values of L less than that corresponding to the "mass-luminosity law" is fully provided for in the diagram.

If the mass of a star changes secularly the path of a configuration in the diagram will move from mass-curve to mass-curve. This in no way affects the general nature of the above conclusions. It will be seen that the radii of the real stars, as indicated in the Russell diagram, Fig. 1, for given L/M, are in general accord with those found theoretically for two-phase configurations on the standard model.[7] We see that the explanations suggested for many of the phenomena exhibited by the stars of nature have nothing to do with the physical nature of the process of energy-generation, or of the existence of stellar evolution other than the possibility of continuous changes of L. Evolution will simply pick out a path in our Fig. 2, a path defined by corresponding values of M and L/M, with the appropriate external radius.

To summarize: the existence of white dwarf stars demonstrates the possibility of a phase other than the gaseous phase. The two-phase configurations that can be constructed, on a simplified model, exhibit many of the characteristics of the stars of nature. By consideration of the two-phase configurations we are led to possible explanations of the observed mass-luminosity-correlation, Cepheid variables, Novæ, giantism of some stars of large L/M and large M, the existence of a second or O-type configuration for large L/M and large M, the dense character of the nuclei of the planetary nebulæ, and the general relationship of dense stars to the non-dense stars of nature.

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[7] To each *locus* in the Russell diagram corresponds a *locus* in our theoretical diagram. The point is whether a star of observed L/M and r_1, has the mass predicted by the theoretical diagram. The theoretical distribution of masses seems to agree very well with what is known about the actual distribution of stellar masses with respect to L/M and r_1, as co-ordinates.

THE GENUS PYRAMEIS WITH SPECIAL REFERENCE TO ITS GEOGRAPHICAL DISTRIBUTION, AND SOME NOTES ON THE CHROMOSOMES AND CYTOPLASMIC INCLUSIONS IN TWO SPECIES.

By

H. C. Regnart, M.Sc., F.Z.S.

Great Britain possesses two representatives of the genus Pyrameis viz. *P. cardui* and *P. atalanta* which arrive almost every year in large numbers from about the middle of May to the end of July; such immigrants produce second broods the members of which die as winter approaches for our climate is too cold for their further success.

If this strong migratory tendency to extend into regions where it cannot permanently establish itself is taken into consideration, *P. cardui* may be said to have a cosmopolitan distribution. It occurs almost everywhere except in South America.

P. atalanta has also an extremely wide distribution, but not such an extensive one as *P. cardui;* its range includes Europe generally, except high Arctic areas, West Africa part of America, and New Zealand (where it has been introduced). It is not found east of the Altai Mountains or in the south of Asia. Reuss (1910) considered *P. atalanta* to be a younger species than *P. cardui,* both more highly differentiated and more physically sensitive.

The general facts of the migrations of *P. cardui* are fairly well known and full details have been collected by Williams (1930); those concerning *P. atalanta* have not been so completely ascertained.

Reuss (1910) made a study of the genus *Pyrameis* in relation to its phylogeny and distribution and mentions some interesting facts in connection with the different species. The Pyrameid group has as a whole a world-wide distribution, and may be approximately divided into two main sections, each containing about half a dozen species. One section may be said to have a general *cardui* facies and the other an *atalanta* facies, or as Reuss designates them a *cardui*-form and an *atalanta*-form group. The *cardui*-form species have a typically Central and South American distribution, e.g. *P. virginiensis, P. carye, P. terpsichore, P. myrinna, P. aequatorialis,* and *P. brasiliensis. P. virginiensis* is found chiefly in South America and in the South United States; *P. carye* has a somewhat similar distribution. *P. terpsichore* is found in Chili; *P. brasiliensis* ranges from Brazil to the Argentine; *P. myrinna* extends through Brazil and *P. aequatorialis* inhabits Ecuador. The *atalanta*-form group includes species which inhabit typically Southern and Eastern Asia, (*P. atalanta* and *P. indica*) Java (*P. dejeana*), Australia and New Zealand (*P. itea* and *P. gonerilla*) and the Sandwich Islands (*P. tammeama*). Each group possesses a powerfully migratory species, *P. cardui* in the first and *P. atalanta* in the second. The two groups have also forms with lesser migratory tendencies; for example, of the South American forms, *P. virginiensis* penetrates across the Isthmus of Panama into the United States. It reaches the Canary Islands and has even reached England on several occasions. *P. carye* also migrates into Southern North America.

P. indica migrates from India as far as Siberia and Japan, and has also been recorded from Madeira.*

In the Canary Islands *P. virginiensis, P. indica, P. cardui,* and *P. atalanta* occur together.

The species of the Pyrameis group are very susceptible to temperature changes during development. For example, if the pupæ of *P. cardui* are subjected to high temperatures they produce forms which appear to be exaggerations of the tropical species; thus *P. cardui* ab. *ocellata* resembles *P. carye.* Similarly, an experimental low temperature form, ab. *wiskotti* Standf. resembles the darker Lapland type (a darker form found in mountain regions and in Lapland) to an exaggerated degree; it also presents an *atalanta*-form margin on the upper side of the hind wings and even a tendency to develop a tail to each hind wing of the Vanessid type. The undersides of the hind wings in this case also indicate a likeness to *Vanessa urticæ*.

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* This Madeiran *indica* form may well be an independent development.

Analogous experimental variations can also be produced in the case of *P. atalanta*. These results seem at first sight to be a direct contradiction of the fact that *P. cardui* and *P. atalanta* are found everywhere practically unaltered by heat or cold, the exception being the Lapland type already mentioned. A form sometimes called *P. kershawi* occurs in Australia, New Zealand and the Sandwich Islands (Reuss 1910). It has blue centres to the eye spots on the hind wings. This form occurs occasionally in other parts of the World (Williams 1930) and has even been recorded from several parts of North America (Bethune-Baker 1910); it is unlikely that this form is due to temperature effects.

The explanation is summarised by Reuss as follows:—"(1) *P. cardui* is by nature a polygoneutic species belonging to the tropical or sub-tropical regions (2) being a tropical species, it is not accustomed to hibernate, and is therefore, easily destroyed by any long period of cold and that (3) for the latter reason it cannot propagate its kind for any length of time in localities where the winters are occasionally severe; (4) therefore only the notoriously migratory habits of *P. cardui* explain the constant recurrence of the species in countries with well marked seasons, such regions being dependent on constant renewal of their stock from the South." Further, Reuss made the assumption that races, if isolated and capable of breeding continuously, had finally by a cumulative process* the environmental effects registered in the germ plasm and genetically "fixed"; but *P. cardui* being of a roaming disposition never stayed long enough for such a process to take place. A similar line of argument applies to *P. atalanta.*

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* Thus, of course, he accepts a Lamarckian point of view.

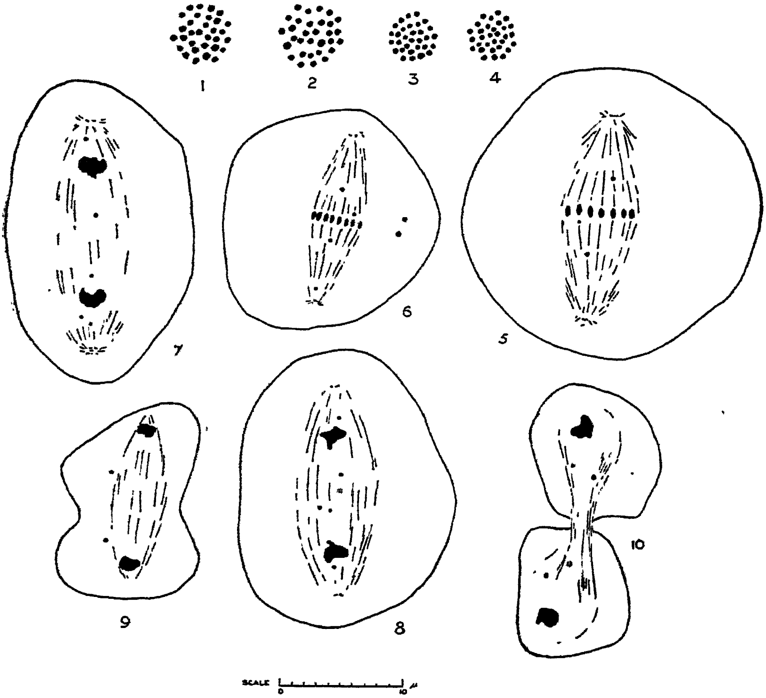
Cytological observations.

In order to ascertain the chromosome numbers of *P. cardui* and *P. atalanta,* a larva of each species was taken in July, and the unpaired reddish brown testes obtained from each transferred to Bouin's fixative. After embedding in wax in the usual manner sections were cut at 6μ thickness and stained with Heidenhain's Iron—Haematoxylin.

A sufficient number of reduction division stages were observed to enable counts of the chromosome number and a comparison of the chromosomes in the two species to be made. For this purpose metaphase plates in both the heterotype and homotype division stages were examined.

Each species was found to have a haploid chromosome number of thirty one—the number expected as it is a very frequently occurring one in the Lepidoptera. The chromosomes were spherical (or oval, at the metaphase stage), and when viewed perpendicularly at the homotype metaphase stage appeared spherical with an approximate maximum diameter of .5μ, some however being slightly less. (Figs. 1, 2. 3, 4). Some of the slightly larger chromosomes appeared in many cases to be arranged at the outer edge of the plate, but this does not always occur. The chromosomes of the two species did not differ appreciably from one another in diameter.

The method of fixing and staining employed rendered a number of cytoplasmic inclusions visible in both species. Heavily staining bodies were observed fairly frequently to be distributed throughout the cytoplasm, but in addition to these the occurrence of several deeply staining bodies attracted notice on account of their frequent proximity to the spindle and their general constancy of position with regard to it and the chromosomes during the various stages of division. One pair of bodies appeared to resemble the micromitosomes described by Gatenby (1917) in *Smerinthus populi, Pieris brassicæ* and some other Lepidoptera when treated for cell inclusions with Flemming's fixative (acid free) or Champy's fluid. In their neighbourhood were located frequently similar but



No 1. P. CARDUI HETEROTYPE METAPHASE PLATE
2. P. ATALANTA " " "
3 P CARDUI HOMOTYPE " "
4. P. ATALANTA " " "
5–10. PROFILE VIEWS OF SPINDLE SHOWING CHROMATOID BODIES,
5 P. CARDUI HETEROTYPE METAPHASE
6. P. CARDUI HOMOTYPE METAPHASE.
7&8 P. CARDUI HOMOTYPE TELOPHASE.
9&10 P. ATALANTA LATE TELOPHASE.

Drawings made with Camera lucida at magnification of 4000.

smaller bodies (Figs. 5 and 6). These bodies were observed in both the first and second division stages.

Examination of the telophase stages of the homotype divisions revealed in addition, again in both species, further bodies situated near the centre of the spindle and apparently also being distributed with some regularity to each daughter cell (Figs. 7, 8, 9, 10). Larger bodies were also observed in the cytoplasm remote from the spindle during these and other stages.

It would be inadvisable at this stage to attempt to classify these bodies, as several distinct types of inclusion appear to be under consideration. Presumably they are all of cytoplasmic origin, but it is desirable to try Feulgen's reaction in order to be able to express a more definite opinion.

An important fact to be noted is that the fixative used contained a large proportion of acetic acid, which dissolves very many cytoplasmic inclusions. According to Gatenby (1919) mitochondria are never clearly seen in sections obtained from material fixed in Bouin. Thus it is improbable that any of even the smallest granules observed are mitochrondrial in nature as they stain so heavily. Some of the larger bodies observed in the general cytoplasm (Fig. 6) resemble the siderophilous granules observed by Gatenby (1917) in Helix cells or the excretory granules described by the same author in Lepidoptera (1917). On the other hand, as already stated, one pair of bodies resembles the micromitosomes (which Gatenby obtained with acid free fixatives).

Then again Guyenot and Naville (1930) in some observations on Drosphila, in which both Flemming's and Carother's fixatives were used (each containing acetic acid), describe siderophilous granules which are distributed to the daughter cells and which bear some resemblance to those found in *P. cardui* and *P. atalanta*. Peacock and Gresson (1931) in a paper on *Sirex cyaneus* described a " chromatoid " body obtained with Bouin as a fixative which gave a negative result with the Feulgen test.

It is interesting to note also the " chromatoid bodies " described by Fasten (1924) which appear during spermatogenesis in various crabs of the genus Cancer when Bouin's and Flemming's fixatives are used. Although these bodies are nearly as large as chromosomes, some of them are quite comparable in behaviour with those seen in *P. cardui* and *P. atalanta*. Different species were found to have different sets of chromatoid bodies situated near the spindle. For example *Cancer productus* gave rise to secondary spermatocytes which each possessed one chromatoid body. In *Cancer gracilis* three types of secondary spermatocyte were produced; one with a single chromatoid body; another with two and a third without any. *C. oregonensis* formed equal numbers of two kinds of secondary spermatocyte, half of them containing one chromatoid body and the others without one.

Unfortunately the lateness of the season precluded the collection of any further material at a suitable stage, and the above brief description is offered as a preliminary statement. The next time larvae can be obtained it is hoped that it will be possible to ascertain the status of the cytoplasmic inclusions described, by using several different standard fixatives and stains.

I have to thank Mr. Johnson of the Wallis Club for the larva of *P. cardui* and Professor Harrison for the *P. atalanta* larva and also for giving me all facilities in the Botany Department.

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NOTES ON THE DISTRIBUTION OF *MACOMA BALTICA* (*L.*) AND *SCOLOPLOS ARMIGER* (O. F. Müller.)

BY

F. BRADY

INTRODUCTION.

In June, 1931 some observations were made upon the distribution of the fauna in Budle Bay.

Budle Bay lies on the north-east coast of Northumberland, approximately three miles south of Holy Island. The bay is two miles long and a mile and a half broad, and at low tide it is left entirely uncovered by the sea as a level stretch of muddy sand.

Two large fresh-water streams, and several smaller ones, cross the mud-flats at low tide.

The mouth of the bay is occupied except at the outlet of the main stream, by a narrow sand-spit which is only covered by the highest spring tides.

Zostera covers large areas of the inner half of the bay, and beds of mussels cover the muds towards the centre.

Over the greater part of the bay the sand was firm, comparatively clean on top, but almost black below a depth of about two inches.

Usually the sand was found to contain a great deal of small shell débris and fragmentary vegetable matter, consisting chiefly of zostera remains.

METHODS.

One series of eight stations was taken from the old oyster pond straight across the centre of the bay. A second series of four stations was taken from Station E to the sand-spit. The positions of these stations will be seen on the accompanying sketch-map of the bay.

At each station a collapsible metal frame was placed on the sand, enclosing an area of a quarter square metre. The sand was then dug out of the "square" to a depth of about nine inches and passed through a series of three sieves of perforated zinc, the diameter of the holes being 5 mm., 2 mm., and 1 mm. Two squares were dug at each station, the mean population being recorded.

A sample of the sand was taken at each station and its consistency determined by the method described by Dr. E. J. Allen. (J.M.B.A., Old Series, Vol. V., 1879-99). A series of sieves of perforated zinc was used, the sizes of the holes being 15 mm., 5 mm., 2.5 mm., 1.5 mm., 1 mm. and 0.5 mm. respectively. The grades recognised are as follows:—

I. Stones.	Inorganic material left on 15 mm. sieve.
II. Coarse Gravel.	,, ,, ,, ,, 5 ,, ,,
III. Medium ,,	,, ,, ,, ,, 2.5 ,, ,,
IV. Fine ,,	,, ,, ,, ,, 1.5 ,, ,,
V. Coarse Sand.	,, ,, ,, ,, 1.0 ,, ,,
VI. Medium ,,	,, ,, ,, ,, 0.5 ,, ,,
VII. Fine ,,	Material which passes the 0.5 mm. sieve, and, when stirred up, settles in one minute.
VIII. Silt.	Material which remains in suspension after one minute.

Grade 1 has been omitted in arriving at the percentage consistency as the weight of the stones was often out of all proportion to the weights of the other grades.

It was found in nearly all cases that fine sand constituted almost the whole of each sample. To facilitate comparison between stations, the amount of silt, which is probably the most important grade in respect of the influence of the sand on its fauna, proportionate to 1000 parts of fine sand was determined in each case.

The pH and salinity of the interstitial water of the sand were determined, the former on the spot, the latter in the Cullercoats Marine Laboratory.

SKETCH MAP OF BUDLE BAY.

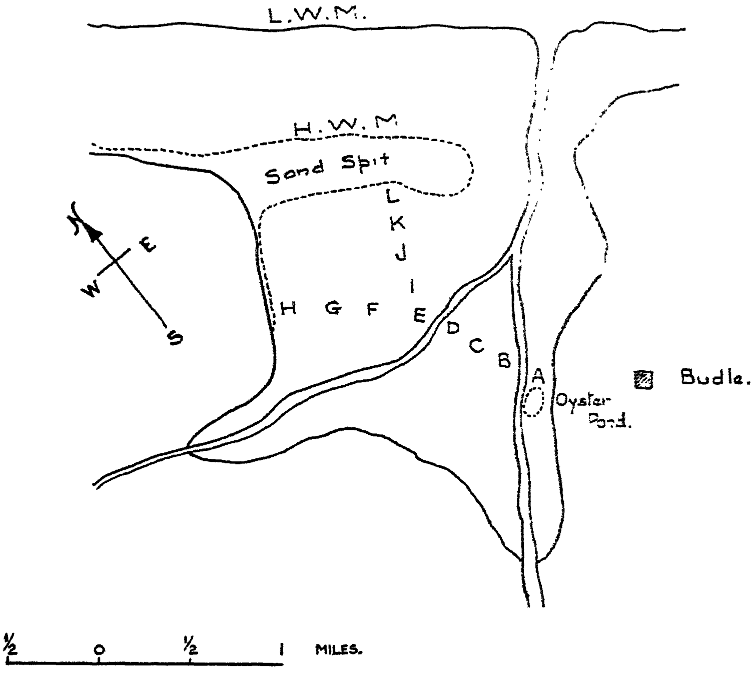
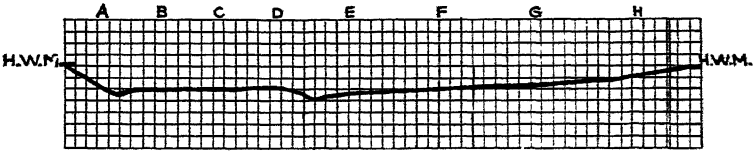


DIAGRAM OF SECTION ACROSS BUDLE BAY SHEWING THE RELATIVE LEVELS OF THE STATIONS.



A brief description of the sand at each station is as follows:—

Station A. Sand firm, fairly clean on top, but very dark below a depth of three inches. Large amount of vegetable and shell débris below three inches.

Station B. Sand firm, black below three inches. Fair amount of vegetable and shell débris below three inches.

Station C. Sand firm, almost black below two inches. Large amount of vegetable matter. Water standing in small pools on the surface.

Station D. Sand firm and clayey, almost black below two inches. Vast quantity of shell débris, coarse to very fine, and a fair amount of vegetable matter below seven inches.

Station E. Sand very unstable and fairly clean for the top three inches, but below that it was very firm, clayey and black. Fair amount of shell débris, but only a little vegetable matter below seven inches. This was the lowest-lying station as will be seen from the diagram of a section across the bay.

Station F. Sand firm and almost black below one inch and a half. Large amount of vegetable and shell débris.

Station G. Sand firm and almost black below quarter of an inch. Fair amount of shell and vegetable débris. Water standing in small pools on the surface.

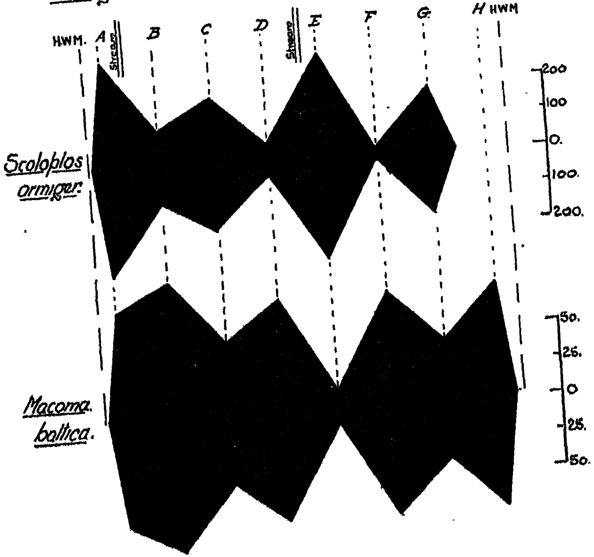
Station H. Sand firm and almost black below one inch. Small amount of shell débris and very little vegetable matter.

Station I. Sand firm and very dark below one and a half inches. Fair amount of shell and vegetable débris.

Station J. Sand firm and very dark below one and a half inches. Fair amount of shell and vegetable

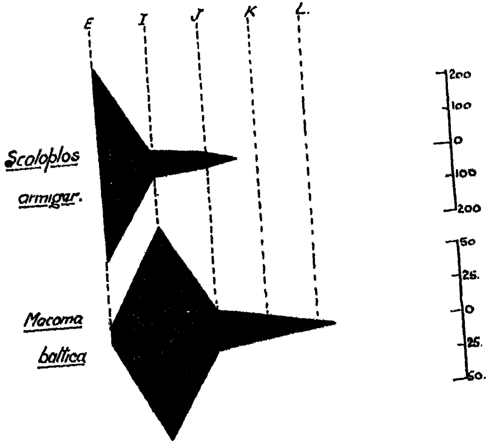
—BUDLE BAY—

Figure shewing the distribution of Scoloplos armiger and Macoma baltica in Budle Bay.



—BUDLE BAY—

Figure shewing the distribution of Scoloplos armiger and Macoma baltica in Budle Bay.



débris. Water standing in small pools on the surface.

Station K. Sand firm and fairly clean throughout. Large amount of shell débris but practically no vegetable fragments.

Station L. Sand firm and fairly clean throughout. Large amount of shell débris but practically no vegetable fragments. This station is higher than station H., and is barely, if at all, covered by high neap tides.

Tables I and II show the distribution of the fauna and some of the prevalent conditions at each station.

Scoloplos armiger and *Macoma baltica* were by far the commonest animals collected.

At first glance their distribution appears very erratic, but a closer consideration reveals an apparent intimate relationship between the two species. The numbers of the one vary inversely with those of the other. This is most strikingly seen when the graphs of the two distributions are compared. (See the accompanying graphs of the distribution of *Scoloplos armiger* and *Macoma baltica*.

Scoloplos armiger was usually found at depths ranging from two to six inches, while the stratum for *Macoma baltica* was from one to four inches.

Both species were very abundant at Station A. Evidently, the conditions prevalent there were exceptionally favourable for both species and, as a result, both occurred in large numbers.

Both animals feed on the same material, i.e. the surface layer of mud and detritus in which they live, *Scoloplos* by means of a soft, extrusible gullet, *Macoma* by means of its long, flexible siphons. Thus, there must naturally be a certain amount of competition between them and it is probable that this is a cause of the relationship between their distributions.

Macoma baltica appears to be the dominant species, *Scoloplos armiger* only being really abundant when the former is relatively few in numbers. On studying the

TABLE I.

BUDLE BAY. DISTRIBUTION OF FAUNA.

Stream

Stream

Name.	Sta. A	Sta. B	Sta. C	Sta. D	Sta. E	Sta. F	Sta. G	Sta. H
Scoloplos armiger ...	608	224	380	104	584	32	400	
Nephthys hombergii ...			2		2			
Nereis pelagica............				2	12			
Nerine foliosa				2				
Arenicola marina ...	32	12	8	32	40	12	20	16
Oligochaeta		150	32	8	8	6	8	8
Nemertea		4	4	10		2		
Cardium edule		52	88	64	24	156		
Macoma baltica ...	152	180	96	152	12	152	80	152
Tellina tenuis			4	8	4			
Corophium volutator ...		36		68	4	120		
pH of Interstitial Water	7·7	7·9	7·8	7·9	7·8	7·9	8·0	7·8
Salinity „ „ „	29·77	32·41	32 22	33·47	31·94	33·61	33·24	28·15
Depth of Water Table below surface ...	8″	1″	Surf.	2″	3″	3″	Surf.	1″
Consistency of Sand ...	%	%	%	%	%	%	%	%
Grade II.	·21	—	—	—	—	—	—	—
„ III.	·26	.04	—	.03	.15	—	—	—
„ IV.	·14	.16	.14	.60	.41	.06	.02	.11
„ V....	·21	.77	.28	1.80	1.16	.18	.10	.49
„ VI.	·78	1.54	.99	3.93	3.12	.54	.60	3.17
„ VII.	97·09	93.75	97.29	89.30	94.77	98.48	98.72	95.51
„ VIII.	1·29	3.78						
Proportion of Silt to 1000 parts Fine Sand ...	13	40	13	48	4	8	6	3

N.B. At Stations C and G the surface water was drained off before the pH of the interstitial water was taken.

TABLE II.

BUDLE BAY. DISTRIBUTION OF FAUNA.

Name.	Sta. E	Sta. I	Sta. J	Sta. K	Sta. L
Scoloplos armiger ...	584	80	24		
Nephthys hombergii ...	2				
Nereis pelagica	12			2	
Arenicola marina ...	40	32	32	24	
Travisia forbesii ...		32			
Ophelia limacina ...			24	4	
Oligochaeta	8				
Cardium edule	24	20	36	12	
Macoma baltica ...	12	156	28	20	2
Tellina tenuis	4	32	12	2	
Corophium volutator ...	4				
pH of Interstitial Water	7.8	8.0	7.9	7.8	7.8
Salinity „ „ „	31.94	32.96	35.27	38.15	39.48
Depth of Water Table below surface ...	3″	3″	Surface	1″	½″
Consistency of Sand ...	%	%	%	%	%
Grade II.	—	—	—	—	—
„ III.	.13	—	—	.09	—
„ IV.	.41	05	.02	.23	.31
„ V.	1.16	.08	.04	.45	.53
„ VI.	3.12	.35	.28	.92	.85
„ VII.	94.77	99.08	98.99	98.09	98.82
„ VIII.	.41	.43	.12	.23	.09
Proportion of Silt to 1000 parts Fine Sand	4	4	1	2	1

distribution of *Macoma baltica* it is found that it generally occurred to the extent of 150 per square metre, but at Stations C, E, G, and J, the numbers dropped considerably. At Station E, where the biggest drop occurred the upper three inches of sand was very unstable, whereas *Macoma,* like other Pelecypods, prefers firmer sand in which it can hold itself in the most advantageous position for the extrusion of the siphons to the surface. At Stations C, G and J the sand was very wet, numerous small pools almost covering the surface, and this, perhaps by preventing the access of air to the sand, may have been the cause for the reduction in numbers of *Macoma baltica.*

At Stations C, E and G there was a well-marked increase in the numbers of *Scoloplos armiger* especially at Station E, where *Macoma baltica* was so scarce. At Stations B, D, F, H and I, where *Macoma baltica* was most numerous, considerable reductions in the numbers of the worm occurred.

The complete absence of *Scoloplos armiger* at Station H and the great drop in its numbers at Station I were probably not due entirely to the abundance of *Macoma baltica* but also to the fact that these Stations were approximately at the normal limit of the range of the species.

No doubt in the absence of one of these species from Budle Bay, the other would be widely and abundantly distributed. Thus the main cause of the fluctuations is the biological environment.

It is an example of a struggle for food between two species in which the physico-chemical environment gives at one place the advantage to the one and at another place to the other.

The author wishes to thank Professor A. Meek for the facilities which enabled him to carry out this work. He is also indebted to Mr. J. Omer-Cooper, Mr. B. Storrow, Dr. H. O. Bull and Mrs. Cowan for much encouragement and advice.

PRELIMINARY NOTES ON THE MORPHOLOGY OF CHROMOSOMES IN PLANTAGINACEAE.

BY

D. M. McCullagh, B.Sc.

Sections of root tips taken from species of *Plantago* show chromosomes which are particularly well adapted for the study of their morphology and individuality. They are few in number, comparatively large, and show definite constant characters in their external form.

Previous work has been done on this family by a number of investigators, but in no case has the chromosome structure been examined in detail. Heitz (1927), who mentions the family, gives the chromosome number for 26 species, but his few drawings offer little chance of comparing the structure of individual chromosomes among the different species. Sinoto has compared the histology of two *Plantago* species, and again gives drawings of metaphase plates, with no reference to the chromosome morphology. So that, although many of the species have been examined before with regard to their chromosome number, their structure is little known.

The family Plantaginaceae consists of three genera: *Plantago,* with 200 species, which has world wide distribution, but mainly in the temperate zones; *Littorella,* with 2 species, from Europe and the Antarctic; and the monotypic genus *Bougeria,* which seems to be confined to the High Andes. The relationships of the family are difficult to define, but most authors agree in regarding them as degraded forms allied to the Tubiflorae.

The members of the family are generally herbaceous, sometimes shrubby with woody stems; the flowers are small and sessile, in compact inflorescences.

At present this research is concerned only with the genus *Plantago*, which Engler and Prantl divide into two sub-genera: (1) EUPLANTAGO, consisting of species which have their leaves spirally arranged, and (2) PSYLLIUM, in which all the species have opposite leaves. These two sub-genera present such striking contrasts, that for this paper two species have been chosen from each for the comparison of their chromosomes: *P. major* L. and *P. tibetica* Hook. and Thomas, from the former group, and *P. psyllium* L. and *P. arenaria* W. and K., from the latter.

P. major and *P. tibetica* have radical broadly ovate leaves, 2-5 ins. long, and thick and leathery in texture; the dense spikes are also long, varying from 3-6 ins. in length, whereas *P. psyllium* and *P. arenaria* have their narrow, fairly small leaves arranged in whorls up the stem, and their flowers grouped in small round heads.

Somatic plates were obtained for these species from sections of root tips which had been prepared under exactly similar conditions. Both Delaunay's (1927) fixative, and Langlet's modification of Navaschin's fixative were tried, but it was decided to use the latter exclusively, for although the solution caused slight swelling of the chromosomes, the constrictions were made very much more distinct, and the cytoplasmic background much clearer, since under this treatment the mitochondria did not take the stain as they did with Delaunay's fixative. In order that there could be no question of the constrictions being artifacts, a number of species had root tips prepared by both methods, and the sections obtained were compared. In every case the structure of the chromosomes corresponded although it was much less clearly marked when Delaunay's fixative had been used.

Heidenhaim's Iron-Alum Haematoxylin was found to be the best stain, for although Brazilin or Gentian Violet made the chromosomes beautifully transparent, the constrictions were again not so obvious as with the Haematoxylin Iron-Alum stain.

The chromosomes are approximately 3 microns long, and therefore with careful preparation the structure is easy to distinguish.

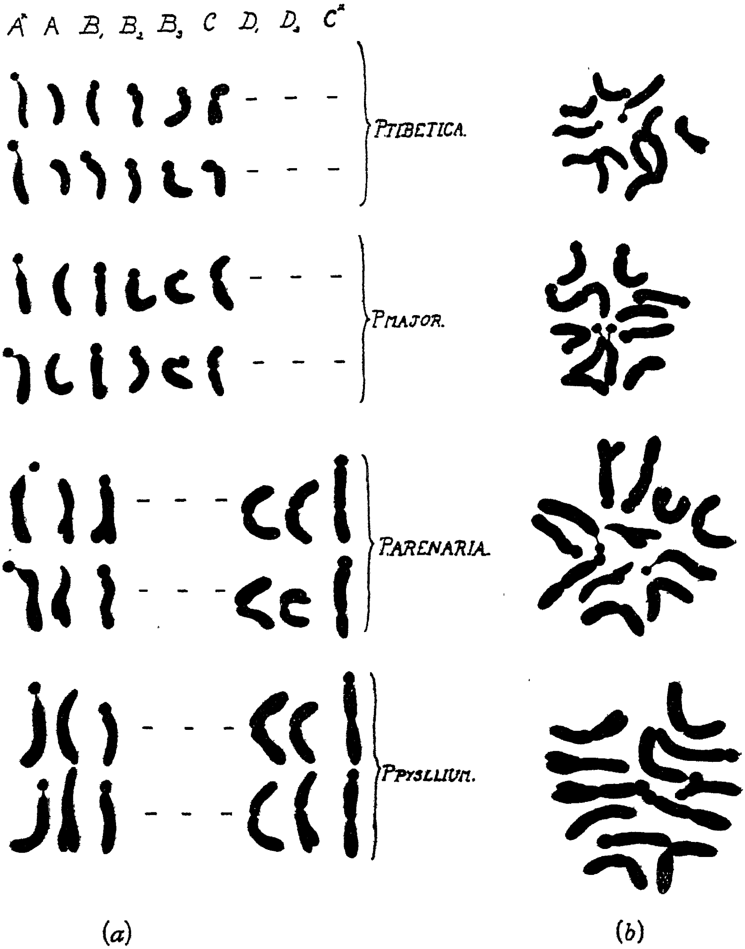


FIG. 1.

(a) Analysis of Somatic Plates. x2500

(b) Somatic Metaphase Plates.

On comparing the chromosomes of *P. major* and *P. tibetica* with those of *P. psyllium* and *P. arenaria*, a number of striking points are noticed. Probably the most obvious is the difference in size (See Fig. 1); this will be dealt with in detail later. The length of the individual chromosomes in each of the complements of these species does not show much variation, but three characteristic features in the external appearance are clearly distinguished, namely, spindle fibre constrictions, secondary constrictions, and satellites.

The term Spindle fibre constriction explains itself. These are the kinetic constrictions of Delaunay; they have also been termed primary constrictions. That they are permanent features of the chromosome and not produced by the spindle fibre, has been shown by both Taylor and Navaschin, who have demonstrated that they are already formed in the early prophase and thus originate quite independently of the spindle. The position of this constriction is constant for each pair of homologous chromosomes in the species concerned, and may be median, submedian, or terminal. The last named case is doubtful as S. Navaschin (1916) showed that such chromosomes which appeared to have only one limb, really have a second, but that this is so small that it appears as a very small granule at the end of the chromosome.

In the two species belonging to the PSYLLIUM group, it will be shown later that one of the chromosome pairs is characterised by two constrictions, a spindle fibre constriction and a secondary constriction, which latter has no connection with the attachment of the spindle fibres, and is an example of the akinetic constrictions referred to by Delaunay. Up to the present time their significance is not well understood but it is obvious that they must be sharply distinguished from primary or spindle fibre constrictions.

In each of the species under investigation, two satellited chromosomes are observed, and according to Taylor these do not seem to be well marked off from the type with constrictions of the second class. The nucleolus theory of Heitz gives further support to this idea.

For the purpose of comparison of chromosomes it is necessary to adopt some sort of a classification. Here, a modification of that employed by Delaunay, which is based on the relative size of the chromosomes, is used. He divided the chromosomes into groups:—large, medium-sized and small; to each type of chromosome he gave a letter, where there are several pairs of one type of chromosome, the distinction may be drawn by putting a figure under the letter, (e.g. B, B_1, B_2). For chromosomes which differed in size but which had the same position of constriction, Delaunay used capital and small letters in order to distinguish them, (e.g. A, a), but I have used only capital letters and in such a case would distinguish the two types by A_1 and A_2.

The letters used in this paper are as follows:—

A*	satellited chromosomes with terminal spindle fibre attachment.
A	non-satellited ,, ,, ,, ,, ,, ,,
B	chromosomes with sub-terminal ,, ,, ,,
C	,, ,, sub-median ,, ,, ,,
D	,, ,, median ,, ,, ,,
C*	,, ,, both primary and secondary constrictions.

By using these symbols the diploid complement can be expressed as a formula, e.g. $2(A^*, A, B_1, B_2, B_3, C)$ represents *P. major* and *P. tibetica,* while $2(A^*, A, B, D_1, D_2, C^*)$ represents *P. psyllium* and *P. arenaria,* (See Fig. 1a).

All four species possess one pair of types A*, A and B. The EUPLANTAGO species have two extra pairs of the B type and one pair of C, whereas the species belonging to the PSYLLIUM group have two pairs of type D, and one of type C*. Type C* is not limited to the sub-genus PSYLLIUM, for it has been observed in at least one of the EUPLANTAGO *P. saxatilis* Bieb.

Two base numbers are found in the Plantaginaceae, namely 5 and 6. In the 20 species examined so far, two diploid and one tetraploid with the base number 5, and 13 diploid, 4 tetraploid and a possible triploid with the base number 6, have been counted. It is seen that the four species under investigation here are all diploids of the second type.

Referring back to the relative size of the chromosomes in these four species, since chromosome size is well known to vary in different tissues, it was necessary to measure chromosomes from corresponding cells, in order to get comparable figures. Plates were chosen from the cortex exclusively, and only chromosomes which were entirely orientated in the optical plane, were measured. Drawings were made by means of a camera lucida and measurements, expressed in centimetres were taken from these with a pair of dividers so that small length spans could be taken where curvature occurred. The results were then converted into microns. Individual chromosomes from five somatic metaphase plates of each species were measured, and very little variation in size was found to occur. The average results for each species are summarised in Fig. 2. From these data it is obvious that the species from the EUPLANTAGO group, possess much less chromatic material per nucleus, than do those of the PSYLLIUM group.

Individual Chromosome Measurements.

Species.	Lengths of Chromosomes expressed in microns.										Breadth
	A*	A	B_1	B_2	B_3	C	C*	D_1	D_2	Total	
P. tibetica	2.7	2.7	2.7	2.7	2.8	2.9	—	—	—	16.5	0.05
P. major	3.0	2.7	2.9	2.9	2.9	3.1	—	—	—	17.5	
P. arenaria	3.5	3.4	3.6	—	—	—	4.5	4.4	3.9	23.7	0.07
P. psyllium	3.4	3.8	3.5	—	—	—	4.5	4.1	3.6	23.0	

FIG. 2.

The difference in chromosome size between the groups seems to be consistent, for two other species of the PSYLLIUM group, *P. cynops* L. and *P. pumila* L., have been examined for their chromosome morphology and promise to give results comparable with *P. arenaria* and *P. psyllium*, while no species yet examined in EUPLANTAGO show chromosomes anything like as long as 3.4μ, which is the measurement of the smallest chromosome in *P. arenaria*.

Before concluding, I wish to express my thanks to members of the Staff of the Botany Department, Armstrong College, for their never failing help and advice.

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List of Research Publications received by the Librarian of the College (in addition to those marked † in the previous section) during the Session ending July 31*st*, 1931.

Elliott, A.: "The Optical Determination of the Relative abundance of Isotopes."

Meek, A.: "Further notes on *Bipennaria asterigera* from the Northumberland Plankton." *Proc. Zool. Soc.*, 1930, p. 355.

Robinson, P. L. and Scott, W. E.: "The Polysulphides of Barium and Calcium." *Journ. Chem. Soc.*, 1931.

Thomas, M.: "The Production of Ethyl Alcohol and Acetaldehyde by Fruits in Relation to the Injuries occurring in Storage, Pt. II." *Ann. Appl. Biol.*, 1931, Vol. 18.

List of Unpublished Theses received by the Librarian of the College

Theses for D.Sc., 1931.

"Contributions to the detailed study of the herring of the southern North Sea."—W. C. Hodgson.

"Part 1. The initiation of the electrical discharge. Part 2. The chemical interaction of ions and the "clean up" of gases at glass surfaces under the influence of the electrical discharge."—James Taylor.

"Manurial problems, with special reference to deficiencies of major essential elements."—Thomas Wallace.

"The intensive system of grassland management, with particular reference to the feeding value of the herbage and its by-products."—S. J. Watson.

Theses for Ph.D.

" On the production and constitution of some polynuclear compounds derived from naphthalene, and on the kinetics of hydrocarbon oxidation."—Robert Spence, 1930.

" The effects of certain rust fungi upon their host plants with special reference to the host cell nucleus."—Elizabeth W. Miller, 1931.

Thesis for M.A., 1931.

" Post-Conquest eleventh Century illumination as exemplified in the MSS. in Durham Cathedral Library. (With special reference to the second part of the Latin Bible dedicated by Bishop William de Carileph.)"—Phyllis Hough.

Thesis for M.Sc.

" A study of the water-relations of *Caltha palustris*."—M. I. Ritson, 1928.

" Part 1. Syntheses of naphthalene ureas. Part 2. Syntheses of derivatives of tetrahydroquinolone."—H. J. Johnson, 1931.

" Some experiments on shellac."—B. M. Letsky, 1931.

" The ring closure of new derivatives of pyrrole."—G. R. Ramage, 1931.

" Studies in the experimental methods of synthesis of bridged-ring nitrogen compounds of the quinuclidine type."—C. R. S. Tenniswood, 1931.

Thesis for B.Sc. Hons., 1923.

" An account of the germination and development of *Euphorbia helioscopia*; and also of the anatomical features of the seed, seedling and mature plant."—Winifred Mary Lowther.

Thesis for M.Com., 1931.

" Production and marketing of forced rhubarb in the Leeds district."—W. T. Smith.

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Nov. 27.	" Algebraic Curves and Surfaces with Assigned Singularities." By Prof. T. R. Hollcroft.
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Jan. 25.	" The Scope of Mathematics." By Dr. H. P. Mulholland.
Jan. 28.	" The Creep of Materials under Stress." A discussion.
Feb. 3.	" A Note on Images in Hydrodynamics." By Prof. T. H. Havelock.
Feb. 3.	" Symbolic Methods of Integration." By Mr. J. L. Burchnall.
Feb. 19.	" New Aspects of Gaseous Combustion." By Dr. R. Spence.
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March 4.	" Some Aspects of the Theory of Stellar Structure." By Prof. E. A. Milne.
March 17.	" On the Chromosome Morphology of Certain Plantagos." By Miss D. McCullagh.
March 17.	" On a case of Pseudogamy in the Geometrid Moth, *Selenia bilunaria*. By Prof. J. W. Heslop Harrison.
March 17.	" The Genus *Pyrameis* with special reference to its geographical distribution and some notes on the chromosomes and cytoplasmic inclusion in two species." By Mr. H. C. Regnart.
April 27.	Horsley Memorial Lecture. By Sir G. Macdonald.
May 3.	" The North Atlantic in the Autumn of 1930." By Prof. A. Meek.
May 3.	" Notes on the Distribution of *Macoma baltica* (L) and *Scoloplos armiger* (O. F. Müller) in Budle Bay." By Mr. F. Brady.
May 30.	" Roman Metallic Objects from the Housesteads." By Mr. E. Birley.
May 30.	" The Metallurgy of the Roman Remains from Housesteads." By Dr. J. A. Smythe.
May 30.	" The Metallurgy of a Bronze Age Celt from Birtley." By Dr. J. A. Smythe.

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A FLANGED BRONZE CELT FROM BIRTLEY, CO. DURHAM.

BY

A. Raistrick, Ph.D., M.Sc. and J. A. Smythe, Ph.D., D.Sc.

During December, 1931 a bronze celt was discovered during the working of the clays at Messrs. Blythe & Co's clay pits, Birtley. The position of the find was not at all clear from description, but a personal examination of the ground soon confirmed that the implement was found during the process of brick making, in clay that had been brought from a position in the pit that could be identified by the works foreman, with certainty. The section at that part of the quarry is mainly cut in about 40 ft. of laminated clay, which was deposited in the late glacial Birtley Lake. This clay is overlain by a few feet of sandy clay and gravel, and has a very irregular upper surface containing frequent deep pockets of gravel. Just before the bronze celt was found, a large section of the laminated clay at the working face of the quarry, had slipped bringing down with it some of the sand and gravel cap, in which the implement occurred. The gravel and sand is of stream origin, in the form of very irregular terrace and delta and of late date corresponding well with similar gravels that occur on top of the laminated clays of many of the Yorkshire glacial lakes. There is clear evidence in Yorkshire that these gravels were forming at the time of the Lardenoisian hunters—makers of the " pygmy " flint implements. The celt of course belongs to a rather late period.

By itself the find is of little significance, but taken with all the other bronze finds of the area, it adds a further link in the chain of evidence of mode of settlement of N.E. Durham. The map (Fig. 1) shows the recorded Bronze Age finds of the area—pottery associated with Bronze Age burials and bronze implements. Pottery

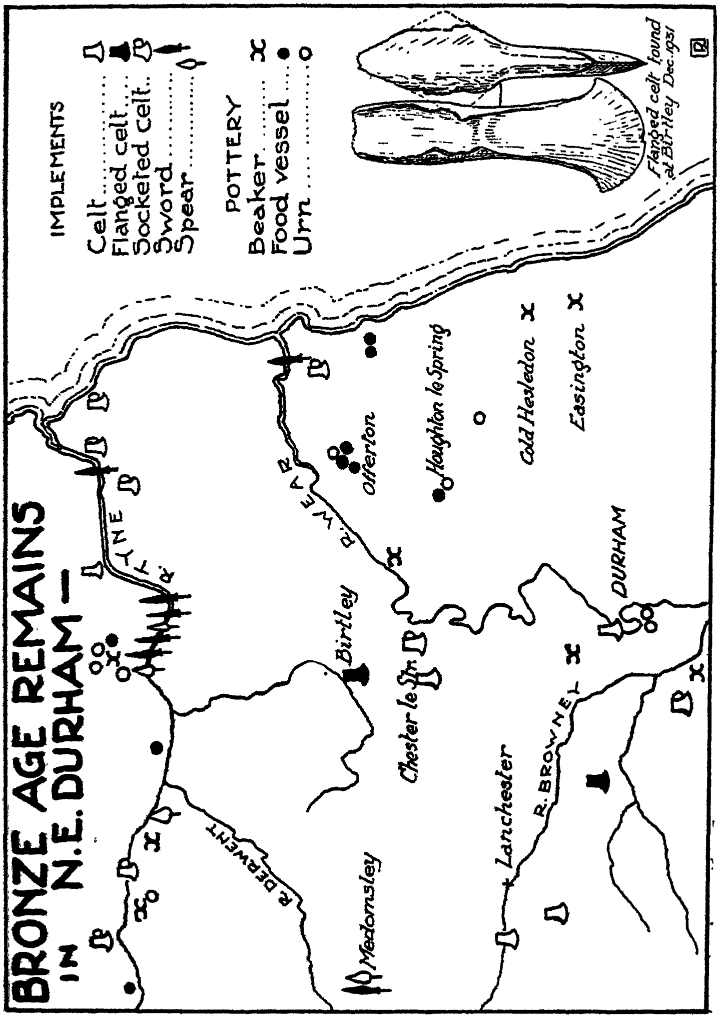
BRONZE AGE REMAINS IN N.E. DURHAM —
IMPLEMENTS
Celt
Flanged celt
Socketed celt
Sword
Spear
POTTERY
Beaker
Food vessel
Urn
Flanged celt found at Birtley Dec. 1931
R. TYNE
R. WEAR
R. DERWENT
R. BROWNEY
Birtley
Chester le Str.
Offerton
Houghton le Spring
Cold Hesledon
Easington
DURHAM
Lanchester
Medomsley

FIG. 1.

has been mapped according to the three types—beaker, food vessel, cinerary urn—ranging between the 19th and 8th Centuries B.C.[1] These three types cover respectively the early, middle and late Bronze period, and are usually associated with definite types of implement. Plain celts belong to the earliest period, along with the flanged celts without stop-ridge (i.e. the Birtley type). Palstaves, looped and socketed spear heads, rapiers etc. belong to the middle period, and socketed celts, leaf shaped swords etc. to the late or urn period. On this chronology it becomes clear from the map that the colonisation of the Wear was mainly early, beakers and early celts forming the majority of finds in the Wear valley, later finds, food vessels, etc. congregating on the higher land of the magnesian limestone towards Sunderland. The Tyne distribution is markedly later, in contrast, spears, socketed celts and leaf shaped swords being dominant. Taken in conjunction with maps of a wider area[2] it becomes clear that the earlier settlement of the area was by both rivers Wear and Tyne, but that in middle and later Bronze Age, comparatively few people penetrated more than the coastal lands of the Wear, while the Tyne became the chief entry. A constant stream of settlers had passed up the Tyne into S. Northumberland and Cumberland, and in the later periods made considerable settlement in the lower Tyne. The Birtley celt seems to fall naturally into the group of finds associated with the Wear valley.

The celt under discussion is a very fine specimen of the flanged celt without stop ridge (see Fig. 2). The wings of the celt have been somewhat damaged in the machinery of the brick making plant, but the rest of the implement is unscathed. The weight is 8 oz., overall length 13.2 cm., maximum width across cutting edge 5.2 cms., width at flanges 2.4 cms. and maximum thickness 1.7 cm. The implement was covered with rich greenish blue patina, the flanges bent inwards, as in use, but cracked and further bent by the accident of discovery. Dr. Smythe has carried out the metallurgical examination of the celt, by a series of hardness tests at the points indicated on the figure by open circle (hardness number alongside) and by microphotos at polished places A to D. A portion of the broken flange near B was analysed and these various results are detailed in the rest of the paper.

---

[1] Raistrick, A. Bronze Age Settlement of the North of England. *Arch. Aeliana* 4th Ser. VIII. pp. 149-165. 1931.

[2] loc. cit. maps., plates XXII, XXIII and XXIV.

Chemical and Metallurgical Examination. By J. A. Smythe.

A small portion of the flange was sawn off and analysed, the results being:—copper 82.73; tin 17.29; total 100.02 p.c. Mere traces of iron and nickel were found.

For the metallographic examination, small areas in places marked A to D on the sketch (Fig. 2) were cleaned, polished and etched. In all cases the structure revealed was that of a bronze rich in tin. The yellow-coloured *alpha* solid solution was in the form of small, equiaxial crystals, frequently twinned and there was no appearance of the cored structure typical of the cast alloy. Many of the crystals, particularly at B were striated and some of the twinned crystals were bent or rounded, thus affording evidence of cold-working. Large pools of the bluish eutectoid of the *alpha* and *delta* solid solutions, scattered throughout the main mass of the yellow *alpha* constituent, testified to the relative richness of the alloy in tin.

These observations indicate that the metal has been cold-worked and afterwards annealed at a comparatively low temperature and that in parts, particularly on the flanges, cold-working has again followed the heat-treatment.

Confirmatory evidence on these points was sought in the study of the hardness of the celt for, in general, cold-working of metals leads to increase in hardness and, incidently, also to increased brittleness. For this purpose several new surfaces were cleaned and polished and ball-

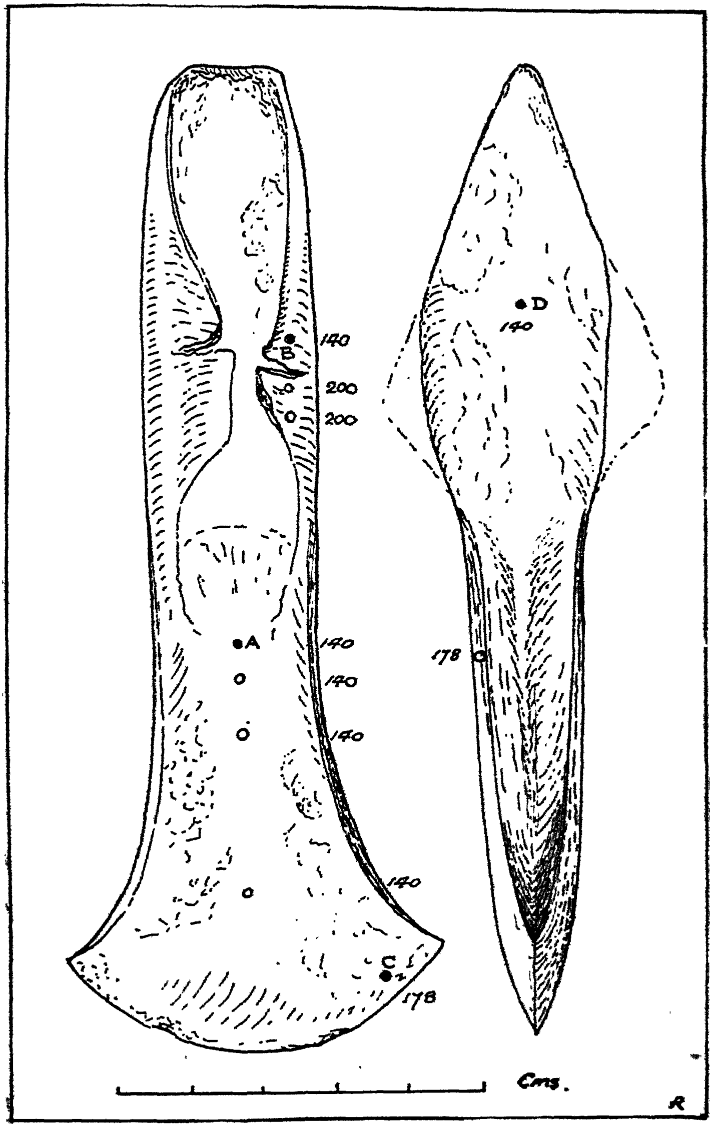

FIG. 2.

impressions made on them, and on those already prepared and used for microscopic examination, by means of the Brinell machine. The Brinell hardness-figures thus obtained are indicated on the sketch (Fig. 2). Mostly they are 140, but the number rises to 178 near the axe edge and on the side of the implement a little above this and attains a maximum value of 200 on the flange, which has clearly been bent over to grip the wooden haft by hammering in the cold. The development of brittleness with hardness here is evidenced by the cracks in the flanged metal.

As a check on the results obtained by the study of the structure and the hardness of the celt, an ingot of bronze of the same composition was made in the laboratory. The cored structure of the cast alloy was removed by annealing at 700°C and also by repeated hammering and annealing at a somewhat lower temperature. The alloy was rather brittle both hot and cold, but it could be worked in the cold provided that the induced brittleness was removed by frequent annealing. Metallographic structures were obtained from specimens which had been worked and then annealed and from others left in the cold-worked condition, which matched in detail those observed on the celt. In the following table, the hardness-values for the celt are compared with those of the made-up alloy in the cast condition and after mechanical and heat-treatment.

Brinell Hardness Numbers.

Celt.	Thick parts	140
,,	Axe Edge and Sides	178
,,	Flange	200
Made-up Alloy.	As Cast	127
,,	After working and annealing	116 to 127
,,	Annealed and severely cold-worked	182

The lowest value for the celt is thus slightly above that of the made-up alloy in the soft condition, i.e. either cast or annealed, which suggests that some strain-hardness is left in the body of the celt and points to continued forging, after the last heating, until the temperature had fallen below that of recrystallisation. The hardness around the axe-edge of the celt is identical, within experimental limits, with that of the made-up alloy, severely worked after annealing; that of the flange exceeds this, as might be expected from the small section of the metal. The cracking of the flange proves that the limit of safe cold-working has been exceeded.

These observations throw some light on the knowledge and methods of the ancient craftsman who made the celt and they bear testimony to his skill in the use of his primitive appliances. It seems probable, from the analytical results, that he had some source from which he was able to draw copper and tin of a high degree of purity. As the finished implement has properties suitable to the purposes of its use, it may be assumed that he melted these metals together in proportions by weight determined by his experience and cast the alloy in a mould, almost to shape, as this would materially lighten his subsequent labours. The absence of casting structure is not inconsistent with this view, for this structure would be obliterated by the working and heat-treatment which followed.

His next task was to shape the rough casting and there can be little doubt that he did this by repeating heating, at not too high a temperature (as indicated by the fine grain of the metal) and hammering not too heavily, particularly in the early stages. The hammering was evidently continued until the metal had cooled considerably that is, had become cold-worked, so that re-heating brought about recrystallisation with the production of twinned crystals. After the last heating, this method naturally left the main bulk of the implement in a slightly hardened condition.

For finishing purposes, the axe-edge was beaten cold and not afterwards annealed, so that it retained its work-hardness. This hardening of the edge was doubtless intentional. Finally, in fitting the haft to the implement, the flanges were hammered cold over the wood and unavoidably hardened thereby and embrittled to such an extent that they cracked in the process. Against this mischance the craftsman had no chance of guarding himself.

I have pleasure in acknowledging the help which my colleague, Mr. C. E. Pearson, M.Met., has given me in the study of this subject.

THE ELIMINATION OF ERRORS DUE TO ABSORPTION IN THE PRISM, AND OTHER CAUSES, IN INFRA-RED ABSORPTION MEASUREMENTS.

BY

D. G. DRUMMOND, M.Sc.

Armstrong College, Newcastle-on-Tyne.

ABSTRACT.—Consideration is given to error arising out of differential absorption of two beams in a prism and to the arrangements in the optical system external to the spectrometer by which this and other errors may be avoided.

In measuring the absorption spectrum of any substance it is naturally desirable to use a prism which does not itself absorb the radiation. This is not always possible, however, and in infra-red work especially it is often necessary to use a prism in a region in which it itself absorbs.

In such a case certain precautions are necessary to ensure that the ratio of radiation intensities as measured with and without the absorbing specimen in the beam will truly represent the fraction of the radiation transmitted by the specimen. If the intensity distribution at the prism face is not uniform and is affected by placing the specimen in position then, in general, the prism will absorb differently in the two cases and the observed curve of intensity ratios will show the characteristic absorption bands of the prism material either as minima or maxima. Further, the ratios will still be in error if the prism shows general absorption without well-defined bands.

Non-uniformity of the intensity distribution at the prism face may easily occur. The source and the slit of the spectrometer are of finite vertical length, that is, they are

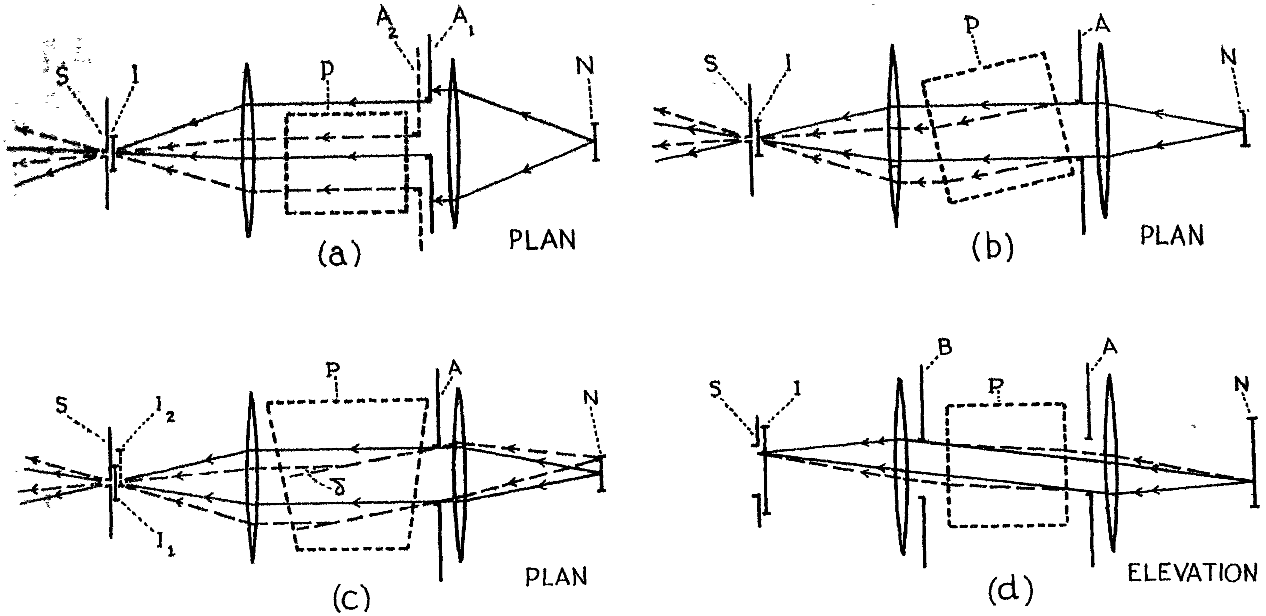

FIG. 1. N = Source of Radiation. A, A_1, A_2, B = Stops. P = Specimen.
I, I_1, I_2 = Image of Source. S = Spectrometer Slit.

(Lenses are shown in all the diagrams, but the argument is unaffected if concave mirrors are substituted for the lenses.)

not simply a point and a pinhole, and in consequence one is not dealing with a single parallel beam but with an indefinite number of such beams arranged fanwise in a vertical plane. It is only within the area of overlap of the extreme component beams that the radiation at the prism face can be of uniform intensity. Outside this area the intensity of the beam will be a maximum in any horizontal plane at the position of the maximum vertical chord of a component beam; that is, at the middle if the aperture is circular. The prism face may extend into and even beyond these outer regions of the beam, especially if the specimen under observation is small, and the system is then open to errors of the type in question. Errors will only occur, however, if the intensity distribution is different in the two cases and such difference exists when the beam is displaced on the prism face as a result of introducing the specimen. This moves the intensity maximum to a greater or less thickness of prism material and the absorption effect on the whole beam is altered.

The position of the beam in the prism is determined, other things being equal, by the direction in which radiation enters the slit and there are various ways in which this direction may be changed. We shall consider only the possibilities in the following particular case:

Suppose that the optical system outside the spectrometer consists of a lens or concave mirror giving rise to a parallel beam into which the specimen can be introduced and that a second lens or mirror focusses the radiation in the plane of the slit. There are then at least three ways in which an alteration in direction of the radiation entering the slit may arise.

(*a*) If two movable stops, one of which moves with the specimen, are introduced into the beam alternately they may not occupy coincident positions when in the beam. This will change the direction of the radiation passing through the slit without displacing the image of the source relative to the slit (Fig. 1a).

(*b*) If the specimen is a plane parallel section but is not placed with its surfaces accurately perpendicular to the beam there will be a lateral shift of the beam by refraction through the specimen (Fig. 1b.) The effect is similar to that described in *a*.

(*c*) If the specimen has plane ends but these are not accurately parallel a deviation, δ, of the beam occurs. The image is then shifted in relation to the slit, so that in addition to the effect due to alteration of beam direction there is an effect due to non-identity of the effective source in the two cases. (Fig 1c).

The change of direction of the beam arising in any of these ways may be avoided by using a single permanently fixed stop on the slit side of the specimen, that is, in the position of stop B in Fig. 1d. This stop must be small enough to embrace only that portion of the beam which, at its plane, is of uniform intensity, for there is already some fanwise spreading.

With this arrangement the possibility is also eliminated of inequalities of aperture such as might occur with alternative stops as in *a* above.

A warning is desirable against using stops at each end of the space into which the specimen is inserted. Only the component beam which runs strictly parallel to the axis can then utilise the full aperture of the stops. For the beams which lie fanwise above and below this, the stops A and B (Fig. 1d.) are mutually obstructive and a falling off of intensity of the image towards the ends of the slit is the result. The interposition of a refracting specimen between the stops has the same effect as shortening the distance between A and B and the loss of intensity at the ends of the slit is thus reduced. The measured intensity-ratios are, therefore, too high.

Refraction in the specimen does not affect the flow of energy through stop B when stop A is absent because, provided that the aperture of the first lens or mirror is adequate, stop B is then filled with light by all beams arising from all points of the source.

A plane, parallel faced specimen should be placed with its faces perpendicular to the axis of the beam. Reflection losses are at a minimum if this is done and, further, the thickness of material traversed is definitely known. The adjustment can be effected by covering half of the source with a screen and receiving on this screen the image of the other half, formed by back reflection from the specimen and refocussed by the first lens. The specimen is adjusted until this image covers the position of the screened half of the source.

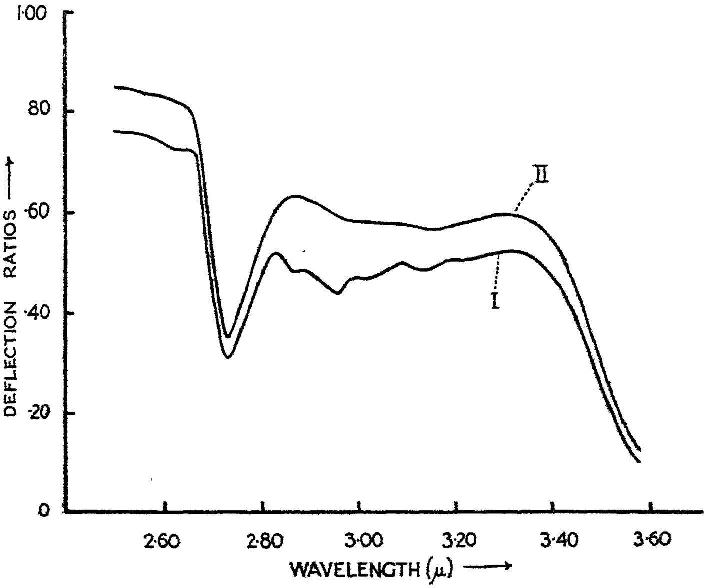

FIG. 2.

Curves obtained in measuring the absorption in a section of fused silica 30 mms. thick, using a crystalline quartz prism in the spectrometer.

I. Without special precautions.
II. With arrangements described.

If the only available specimen has faces which are not truly parallel the best that can be done, short of repolishing the faces, is to proceed as above, when two images formed by back-reflection will, in general, be seen. Rotation of the specimen about the axis of the beam will cause corresponding points of these images to rotate about each other and in two positions the images will overlap in a vertical line. At these positions the wedge angle of the specimen is pointing vertically upwards or downwards and the deviation of the transmitted beam is confined to the vertical plane. If the image of the source is long enough to cover the slit and overlap the ends appreciably the error due to such a vertical shift is small compared with the effect of a horizontal shift.

In Fig. 2 an example is given of the effect of neglecting the precautions above described. The infra-red absorption in a specimen of transparent fused silica 30 mms. thick was measured using a crystalline quartz prism and the bands characteristic of crystalline quartz in the 3.0μ region appeared in the deflection-ratio curve (Fig. 2, curve I). These bands were not of constant intensity in different series of measurements and it was suspected, therefore, that they were not due to the vitreous silica.

The specimen was found to have non-parallel ends, the wedge angle being ½ to 1 degree. On using a fixed stop on the spectrometer side of the specimen and making the other adjustments as described, the crystalline quartz bands disappeared and also a considerable difference in the general level of the curve was observed (Fig. 2, curve II) showing that in work of this sort the precautions described are very necessary if accurate results are to be obtained.

I wish, in conclusion, to record my thanks to Dr. J. J. Fox of the Government Laboratory and to Professor W. E. Curtis of Armstrong College for their encouragement and for helpful discussion of this paper.

THE USE OF HIGH FREQUENCY ELECTRIC FIELDS TO RAISE BODY TEMPERATURE.

BY

W. E. CURTIS, D.Sc., (Professor of Physics) and
S. F. EVANS, M.Sc.
Armstrong College, Newcastle-on-Tyne.

Introductory.

There have been in recent years considerable developments in the production of high frequency oscillating currents, both in the direction of higher frequency and increased power. Thanks to the advances which have been made in the construction of wireless valves it is now possible to maintain continuous oscillations of a frequency of 10 million per second (corresponding to a wavelength of 30 metres) or higher on a power of many kilowatts. It has been noticed that persons in the vicinity of such circuits are liable to experience marked heating sensations, and this has led to investigations of the phenomenon with a view to its possible utilisation for medical purposes.

Carpenter and Page in America[1], have reported elevations of temperature amounting to 6°F. by such a method, but so far as we are aware no similar work has been undertaken in this country. As we had in this laboratory the necessary apparatus for generating high frequency oscillations it seemed therefore worth while to carry out some preliminary tests of their suitability for this purpose.

Theoretically there are two alternative methods available, which may be termed the electromagnetic and the electrostatic. In the former the conductor in which heat is required to be generated is placed inside a coil carrying the oscillatory current, and currents are induced in it by the rapidly varying magnetic field. The induced currents generate heat on account of the resistance of the conductor, and if this heat is prevented from escaping very high temperatures can be attained. This is the principle of the so called "induction furnace." Although very efficient the method does not seem suitable for the present purpose chiefly on account of the size of coil necessary to surround the body.

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[1] Carpenter and Page, Science 71, 450, 1930.

In the electrostatic method the conductor is placed between the plates of a condenser to which the high frequency potential difference is applied. The alternating electric field then produces an oscillatory surge of current in the conductor and therefore generation of heat as before. If the substance used is only a partial conductor a second factor comes in, namely "dielectric heating," due to the direct action of the oscillating field on the molecules of the body. The total heat generated is the sum of these two factors.

This would appear to be a much more convenient method to apply to the human body, since it can quite readily be placed between the plates of a condenser, and this is the method which was used by Carpenter and Page. It is generally similar to the diathermy method, except that the electrodes are not in contact with the body. It would be impracticable to affix electrodes covering sufficiently large areas of the body to give a general as distinct from a localised heating effect, whereas the condenser method necessarily gives a more or less uniformly distributed generation of heat, with perhaps a maximum in the interior of the body.

This is the great advantage of such a method, as compared with the communication of heat from without, if a general elevation of body temperature is desired. The temperature of the body can be raised by surrounding it with air at a sufficiently high temperature, but the rate of rise is comparatively slow unless an uncomfortably high temperature is employed, and profuse perspiration is induced. Taking a rather different point of view, one may say that whereas the body is equipped to resist the communication of heat from without, both by reason of its low thermal conductivity and by the process of perspiration it is not able to dispose rapidly of heat generated in its interior. The high frequency method, or " radio thermy " as it has been termed, therefore appears to possess valuable possibilities for this purpose.

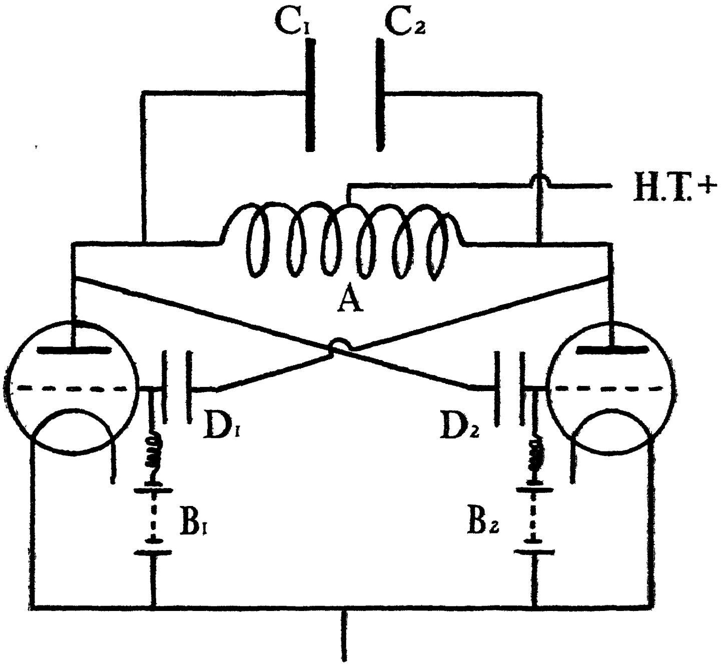


FIG. 1.

Description of Apparatus.

The circuit used is shown in Figure 1. It is of the symmetrical or " push-pull " type, employing two similar valves (type MT9F made by the General Electric Company) each dissipating approximately one kilowatt. Some preliminary experiments using two 250 watt valves failed to give any measurable effects. Both filaments and anode circuits were supplied with raw alternating current from transformers, at 17 and 4,000 volts respectively, the corresponding total currents being about 26 and 0.5 amps. The coil A connecting the two anodes consisted of a helix of 10 turns of ¼ inch copper tubing, 4 inch diameter with a spacing of approximately ½ inch between successive turns. The condensers, D1, D2, coupling the grid of one valve to the anode of the other were each made up from 12 sheets of aluminium 6 inches by 6 inches by 1/64th of an inch spaced ½ inch apart, but the value of this capacity is not at all critical. B1 and B2 are grid bias batteries, but since preliminary tests showed that the valves worked well with grids connected directly to the filaments the batteries were dispensed with. They might be required with other types of valve, however.

The whole of the above apparatus was arranged on the floor of the laboratory immediately beneath the box, the ends of which rested on two tables. This proved very satisfactory from two points of view. First, it minimised the risk of accident from the high voltage employed, since the apparatus was well out of the way, and second, the leads to the box were as short as possible, some 3 feet, which was advantageous in regard to the high frequency efficiency.

The condenser plates, C1 and C2, were made of sheet copper 32 inches by 10 inches fastened on plates of ebonite 36 inches by 14 inches by 3/16ths of an inch. These were fixed to the sides of the box on spacing pieces of ebonite 3/16ths of an inch thick, with the electrodes inside. Care was taken that there should be no exposed metal at high voltage. For instance the terminal by which the oscillatory current was led to the electrode was fitted with an ebonite cap.

The box itself was built of celotex on a rectangular wood frame as shown in Figure 2. The sides and ends slid in grooves in the wooden uprights, so that they could easily be removed when required, and the lid rested in position, being provided with a wooden rim so as to make it moderately airtight. Canvas webbing 2 inches wide was stretched across the base frame at intervals of 2½ inches to support the body without obstructing too much the access of air. It was found best to tack this down on the outside edges of the frame, not inside the box, or the patient was liable to get high frequency burns by accidental contact with the tacks. In general the amount of metal

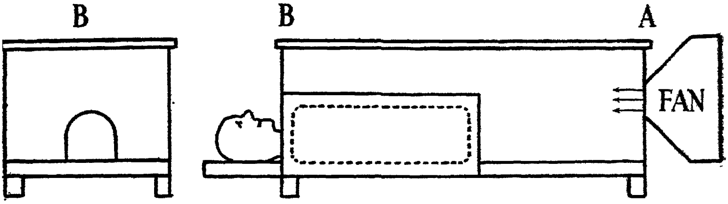


FIG. 2.

used in construction was kept down to a minimum. The end A of the box was made of flat asbestos cement sheeting (celotex being inflammable) and a heating mat (40 ohms. to carry 4 amps, made by Messrs. Cressall Ltd., 31 Tower Street, Birmingham) was fixed as shown over an aperture slightly smaller than itself. The current through it was supplied from 240 volts D.C. mains and regulated when necessary by a 40 ohm. rheostat. It was usually kept at from 5.2 to 5.5 amperes. An ordinary ventilating fan working at low speed was fixed just outside the mat so that it blew a steady stream of hot air into the box. Additional heating was provided by two 100 watt lamps, which were fixed one on either side wall near the end A. Although these were originally introduced merely because a more powerful heating mat was not available at the moment, they were eventually retained, as in addition to providing a better distribution of heat supply they illuminated the alcohol thermometer T so that it could be read without removing it. This was hung on the inside of the end B, which was of celotex, with a hole of suitable shape for the neck of the patient, but not fitting very closely, so that it was possible for the patient to get a hand out. A towel was hung over the aperture to prevent a blast of hot air issuing on the patient's face, and served also for removing perspiration as required. A number of small holes were made in the walls at the head end to permit the escape of moist air. The thermometer was read by opening slightly a small trap door in the lid. The temperature varied considerably at different points in the box, and the thermometer was very sluggish in action. Consistent readings were only obtainable when it was kept fixed in one position, and this was accordingly done. The temperature of the air immediately adjacent to the body was probably appreciably higher than that recorded by the thermometer. It is perhaps worth noting that a mercury thermometer should not be used, since the mercury, being an electrical conductor, may be subject to high frequency heating effects as in the case of the body. But it was found that an ordinary clinical thermometer was not affected in two minutes, the period used in taking the patient's temperatures.

Experimental Details.

The construction of the box and the experimental method generally was based in the first instance on the particulars given in the American paper mentioned above. Certain modifications were introduced as experience was obtained of which the most important was in the heating arrangements. Following the Americans' method we at first used an internal heater (an electric hair dryer), the box being entirely closed. With the low power (½ kilowatt) set rises of temperature of several degrees were obtained with some subjects, but the results were variable and the rise of temperature irregular. It would remain fairly steady at first, say for an hour or thereabouts, and then begin to rise rapidly. At the same time discomfort began to be experienced, and increased steadily, becoming very marked at an oral temperature of 101°F. or so. It appeared probable that this was due to the air in the box having become saturated with moisture, thus preventing the evaporation of perspiration, the chief means whereby the body is enabled to dissipate surplus heat.

Steps were accordingly taken to prevent the air becoming saturated, by providing a steady supply of warm air from outside, and allowing the moist air to escape. This was quite successful, and the temperature graphs subsequently obtained were much more satisfactory, rising steadily from the beginning of the experiment.

The primary object of the work being to find whether appreciable effects could be obtained with the electrical apparatus available, comparatively little effort was made to determine the most efficient conditions where this would have involved spending much time in tests. It is probable, for example, that the magnitude of the effects depends on the oscillation frequency, but this was kept constant at about ten million per second, corresponding to a wavelength of 30 metres. The size and position of the electrodes are other important factors. They could no doubt be brought closer together with advantage, but only at some sacrifice of comfort. The best position for them would certainly be immediately above and below the body, but again this would be less comfortable, besides reducing the symmetry of the oscillatory circuit, a desirable if not essential feature. The arrangement used was also the safest, having regard to the fact that the electrodes were connected directly to the 4,000 volt supply.

A considerable increase of power could have been obtained by using direct current instead of alternating, or even by rectifying the latter supply, but the necessary apparatus was not available. Every care was taken to avoid possible sources of disturbance. The subjects experimented upon were all apparently in perfect health, and both oral and rectal temperatures were observed at intervals of 15 minutes from the commencement of the experiment, both thermometers being left in position for two minutes in every case. The air temperatures were read simultaneously, or more frequently if they were fluctuating. This sometimes occurred due to variations in the mains voltage.

In all cases two runs were taken on separate occasions, one with high frequency current and hot air, and a second of the same duration with hot air alone at as nearly as possible the same temperature as before. This was necessary in order to separate the effects of high frequency and hot air, which were usually of quite comparable order of magnitude. A good many preliminary experiments were made using different air temperatures from 100°F. to 130°F. The latter was adopted for the final runs, since it appeared to be about the maximum which could be endured for some hours continuously without serious discomfort. This was also the air temperature used by the American workers. It should be noted however, that higher temperatures were not actually tried, since they could not be obtained with the apparatus available.

The experiment was continued in each case until the oral temperature had reached about 102°F. unless the subject wished it to terminate earlier.

Experimental Results.

The results obtained with eight subjects (A-E male, F-H female), are tabulated below, and also shown graphically. It will be seen that there are considerable differences in the individual behaviour but good agreement between the oral and rectal rates of rise. The initial temperatures taken immediately at the beginning of the experiment frequently differed considerably from the normal values, but these discrepancies practically always disappeared in the first quarter of an hour, and the rates of rise have therefore been calculated from the difference between the latter reading and the final one. The results obtained with hot air alone have not been plotted, but were generally similar except for the smaller magnitude of the effect. They are included in the table. In several cases the subject was weighed before and after the run, and losses of from two to four lbs. were recorded. Although a certain amount of discomfort was sometimes felt during the last quarter of an hour, this was never serious, and did not persist after the termination of the experiment, although a slight and quite temporary lassitude was sometimes experienced. The sensation of discomfort was not correlated with the rate of rise of body temperature, but appeared to be purely an individual phenomenon. Subject G, for example, who gave much the most rapid rates of rise, showed least sign of discomfort.

Subject	Time.	With H.F			Without H.F.		
		Max. Temp.		Mean rate of rise	Max. Temp		Mean rate of rise
		Oral.	Rectal.		Oral.	Rectal	
A	90 mins.	102·1	102·8	2·65	100·5	101·4	1·0
B	75 „	102·0	102·1	2·9	100·1	100·9	1·0
C	115 „	102·1	103·2	1·95	—	—	—
D	90 „	101·8	103·2	2·1	99·6	100·7	1·0
E	75 „	101·2	102·8	1·7	99·5	100·8	·4
F	75 „	102·4	102·3	3·2	100·7	101·2	1·45
G	45 „	103·1	103·5	4·7	101·2	101·3	2·3
H	90 „	102·4	103·1	2·25	100·7	101·2	1·3

The temperatures are expressed in °F. and the rates of rise in °F. per hour.

Blood pressures were measured by Dr. Whateley Davidson at the beginning and end of the experiment in case C. The systolic dropped from 142 to 98 and the diastolic from 65 to 30 mms.

A further experiment was performed on Subject G with the object of seeing if the rate of rise was maintained over a longer period. This was the case, temperatures of 104.7 and 104.4°F. being attained after 75 mins. corresponding to a mean rate of rise of 4.5°F. per hour. The blood pressures at the end of the first quarter of an hour and at the termination of the experiment were 102/60 and 88/38 respectively. We are indebted to Dr. A. G. Ogilvie for his co-operation on this occasion.

Discussion of Results.

The results provide a conclusive answer to the question whether a high frequency set of the type available could be utilised for raising the body temperature. The effects

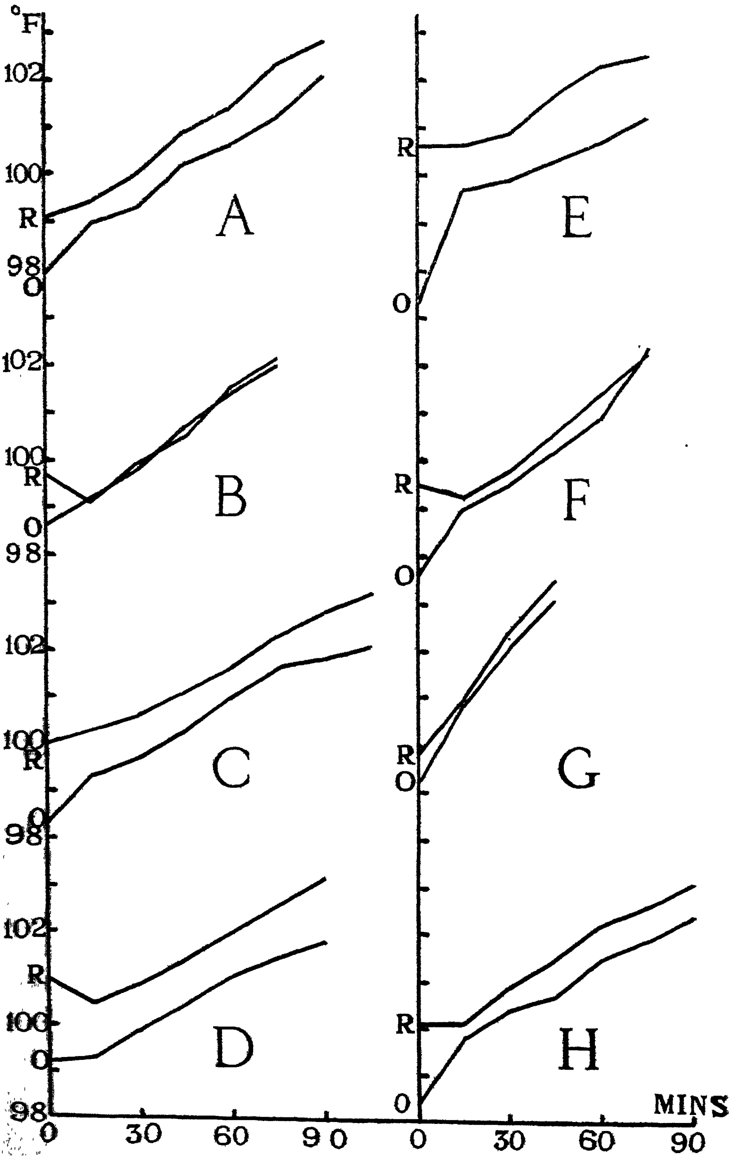

°F
102
100
R
98
O
A
102
100
R
O
98
B
102
100
R
O
98
C
102
R
100
O
98
D
R
O
E
R
O
F
R
O
G
R
O
H
0
30
60
90
0
30
60
90
MINS

FIG. 3.

were quite definite in all cases, although varying considerably in magnitude with different individuals. The curves suggest that much higher temperatures might have been attained if the experiments had been prolonged, but in the absence of medical supervision it was not thought advisable to produce rises of more than about 4°F.

The effect of hot air alone was quite considerable, giving rises averaging a little less than half those due to high frequency and hot air, and it might perhaps be thought that similar results to the above could be obtained either by prolonging the exposure to hot air (at 130°F.) alone or in the same time by using air at a higher temperature. Either procedure is open to objection, however, the former on the ground of excessive time required for treatment and the latter on account of the discomfort involved. The main advantage of the high frequency method of heating is that it accelerates the temperature rise without adding appreciably to the discomfort experienced. There is no doubt that a more powerful high frequency set would give a more rapid rise, and some increase in this direction is desirable. But apart from the increase in the cost, both of valves and transformers, a much higher power would be likely to give objectionable electrical effects. For instance, as recorded by the American workers, drops of perspiration, being good electrical conductors, are liable to produce local high frequency burns. In our case it was usually found that slight but unpleasant burns occurred on touching the body or legs with the fingers.

We have made rough calculations of the proportion of the heat input utilised in evaporation of perspiration, with the following results.

An average loss of weight of 3 lbs. in 90 minutes, *i.e.* about $\frac{1}{4}$ gm. per sec., requires the supply of 142 cals. per sec., taking the latent heat at 130°F. as 568 cals. per gm. The actual heat supply to the air (*i.e.* excluding heat generated in the body by high frequency) was about 1400 watts, or 330 cals. per sec. Hence nearly half the heat supplied was utilised in evaporating perspiration. To check this roughly we performed a blank experiment using a dummy body, and found as expected that the temperature rose much higher with the same heat supply as before. We were not able to measure the steady temperature attained as it would have been much above the highest reading (145°F.) on the alcohol thermometer.

If the method is to be applied for medical purposes it may be necessary to maintain the rise of temperature at a steady value for some time. The best way of doing this would probably be to reduce the air temperature by a suitable amount. This is one of the directions in which further work is desirable. Another procedure which should be tried is to wrap the body closely in absorbent heat insulating material and subject it to the high frequency field without other heating. There is also the question of the optimum wavelength requiring investigation.

It is thus apparent that a good deal of purely physical work remains to be done before the method can be regarded as fully available for medical purposes, and it is hoped to continue on the lines indicated.

In conclusion, we desire to express our thanks to Dr. Whately Davidson for his interest and advice on the medical side of the work. We are deeply indebted also to the past and present students who have assisted in the investigation by volunteering to act as subjects.

A RECORD OF THE *ANTHRACOMYA LIBRATA* GROUP FROM THE COAL MEASURES OF NORTHUMBERLAND.

BY

WILLIAM HOPKINS, M.Sc., Ph.D., F.G.S.

Throughout this paper, the following abbreviations are used to indicate some of the authors of the species: (Tr.), A. E. Trueman; (D. and Tr.), J. H. Davies and A. E. Trueman; (Dix and Tr.), E. Dix and A. E. Trueman; (Wr.), W. B. Wright; (Sow.), J. de C. Sowerby.

Introduction.

In 1928, I applied the zonal scheme of Mr. J. H. Davies and Prof. A. E. Trueman[1] to the Coal Measures of Northumberland and Durham[2]. Four zones were recognised as follows:—

1. Zone of *Anthracomya phillipsi.*
2. Zone of *Anthracomya pulchra* and *Carbonicola similis.*
3. Zone of *Anthracomya modiolaris.*
4. Zone of *Carbonicola ovalis.*

As a result of continued collecting, fuller details of the vertical and lateral distribution of the genera *Carbonicola, Anthracomya,* and *Naiadites* have gradually been established and the results achieved have been recorded in various papers in 1929[3], 1930[4] and 1931[5].

In discussing the 1930 paper, Dr. W. B. Wright commented upon the absence of certain forms which were characteristic of the Lancashire group of Coal Measures. He referred in particular to the apparent absence of the remarkable Ashclough fauna of Lancashire which contains *Anthracomyas* of the *librata* group and *Carbonicola radiata* (Wr.)[6, 7]. Prof. A. E. Trueman and Dr. D. A. Wray have recorded members of the *librata* group from Yorkshire[8] while Prof. Trueman and Mr. W. D. Ware have recorded them from South Wales[9].

Since 1930, I have found some of the hitherto missing forms at Blyth in Northumberland and it is proposed to record these in this present note.

New faunal horizons proved at the Blyth Bates sinking.

Through the courtesy of Mr. S. Bates of the Cowpen Coal Company, I have been enabled to collect and examine material tipped from a sinking now being constructed at Blyth. Material has thus been obtained from strata which otherwise would have remained inaccessible. The strata passed through and the horizons of the fossil bands relative to the High Main Seam are shown in the accompanying figure. The material was collected from shales at heights of 111-110; 108; 106-105; 99-98 and 96-94 feet above the High Main seam *i.e.* from the Similis-Pulchra Zone.

The specimens found at each horizon are as follows:

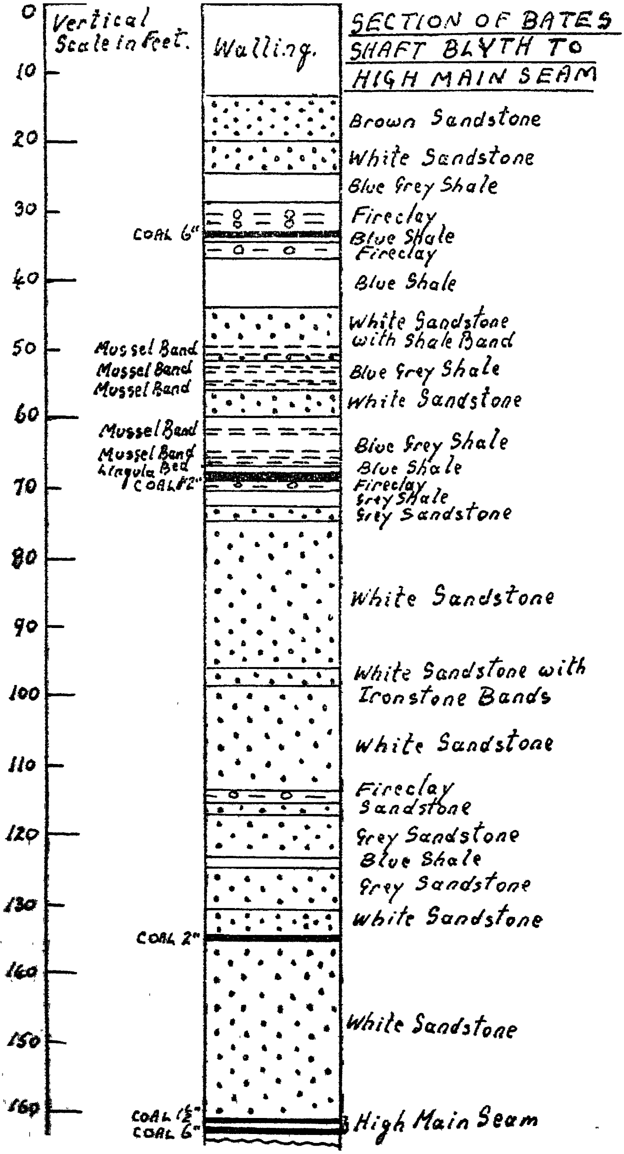
Height above High Main Seam.

111-110 Feet.	*A. cymbula* (Wr.), *Anthracomya* sp. *C. acutella* (Wr.), *C. concinna* (Wr.), *C. atra* (Tr.), *C.* cf. *atra* (Tr.), *Carbonicola* sp.
108 Feet.	*A. cymbula* (Wr.), *Anthracomya* sp. *C.* cf. *lateralis* (Tr.), *C.* cf. *radiata* (Wr.), *C.* cf. *concinna* (Wr.), *C. fulva* (D & Tr.), *C* cf. *fulva* (D. & Tr.), *C. atra* (Tr.), *C. aquilina* (Sow.), *Carbonicola,* sp. *Carbonicola,* sp. nov?
106-105 Feet.	*A. cymbula* (Wr.), *A. rubida* (Tr.), *C. acutella* (Wr.), *C. concinna* (Wr.), *C.* cf. *concinna* (Wr.), *C. aquilina* (Sow.), *C.* aff. *aquilina* (Sow.), *C.* sp. cf. *similis* (Brown).

99-98 Feet.	*A.* aff.*oblonga* (Wr.), *A. cymbula-librata* (Wr.), *A.* aff. *rubida* (Tr.), *C.* cf. *atra* (Tr.)
96-94 Feet.	*A. cymbula* (Wr.), *A.* aff. *cymbula* (Wr.) *A. oblonga* (Wr.), *A.* cf. *oblonga* (Wr.), *A. librata* (Wr.), *A.* cf. *librata* (Wr.), *A.* aff. *rubida* (Tr.), *A.* cf. *rubida* (Tr.), *A.* cf. *adamsi* (Salter), *A.* sp. *pulchra* (Hind.), *Anthracomya* sp., *C.* cf. *radiata* (Wr.), *C. aquilina* (Sow.), *C.* aff. *aquilina* (Sow.), *C.* cf. *aquilina* (Sow.), *C. fulva* (D. & Tr.), *C.* cf. *fulva* (D. & Tr.), *C. concinna* (Wr.), *C.* aff. *concinna* (Wr.), *C.* cf. *concinna* (Wr.), *C.* cf. *atra* (Tr.), *C. acutella* (Wr.), *C. similis* (Brown), *C.* cf. *similis* (Brown), *C. turgida* (Brown), *C.* cf. *turgida* (Brown), *Carbonicola* sp. nov? *Carbonicola* sp. *N.* cf. *daviesi* (Dix & Tr.), *N.* aff. *producta* (Brown), *Naiadites,* sp.

The *Anthracomyas* usually occur in distinct bands although occasional forms occur in association with *Carbonicola.* Intermediate forms of the members of the *librata* group are common. *A. rubida* is not abundant while *A.* cf. *pulchra* occurs sporadically. The same applies to *A. adamsi and Anthracomya* sp.

Examination of the fossil lists given and particularly of the lowest one, suggests a striking similarity to the Ashclough fauna of Lancashire which Dr. Wright has found to be particularly useful for seam correlation purposes[6, 7]. However, *C.* cf. *radiata* (Wr.) is not abundantly developed. The specimens in my possession show only faint radial striae, but otherwise agree closely with Dr. Wright's definition of the species. *C. similis* (Brown) anl *C. turgida* (Brown) are not abundantly represented. The bulk of the fauna is made up of the members of the *librata* group of *Anthracomya* and forms resembling or closely related to *C. aquilina* (Sow.). *C. acutella* (Wr.), *C. concinna* (Wr.), *C. fulva* (D. & Tr.), *C. atra* (Tr.) and *Car-*



SECTION OF BATES SHAFT BLYTH TO HIGH MAIN SEAM *bonicola* sp. nov. The occurrence of the *librata* group is a new record for the Northumberland and Durham Coalfield. The range of the group is not yet known.

At the base of the lowest band there is a bed of blue shale containing *Lingula mytiloides* (Sow.) and a few ostracods, and this probably represents quasi-marine conditions. The underlying strata down to the High Main seam are barren of shells.

The records given fill in a gap in the succession of the non-marine shells of this coalfield, particularly with regard to forms of *Anthracomya.* Further knowledge however is still required concerning the fauna at the top of the Similis-Pulchra Zone, the Phillipsi Zone and the *Anthracomyas* of the Modiolaris Zone. The only known members of *Anthracomya* from the Modiolaris Zone are *A. modiolaris* (Sow.) and *A. williamsoni* (Brown) although characteristic forms of *Carbonicola* occur.

Acknowledgements.

I wish to express my thanks to Prof. A. E. Trueman who checked some of my specific determinations. My thanks are also due to Mr. S. Bates and the Cowpen Coal Company for affording facilities for collecting the material and for granting permission to record the section from which the specimens were obtained. I am also indebted to the foreman sinker, Mr. Roddam who assisted in the checking of the depths of the material, and to Mr. G. O'Neill who assisted in the collecting of the specimens.

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ADDITIONS TO OUR KNOWLEDGE OF CHROMOSOME NUMBERS IN THE LEPIDOPTERA.

By

H. C. Regnart, M.Sc., F.Z.S.

Recently I have undertaken investigations into the chromosome numbers in representatives of the Lepidopterous genera:—Papilio (Fam. Papilionidae); Halias (Fam. Hylophilidae); Acronycta, Ochria, (Fam. Caradrinidae); Opisthograptis, Phigalia, Metrocampa, Hygrochroa, Selenia (Fam. Selidosemidae); Odontosia, Phalera (Fam. Notodontidae); Depressaria, (Fam. Oecophoridae); Hyponomeuta (Fam. Hyponomeutidae): the end in view was to ascertain whether the chromosome numbers would assist in the construction of a phylogenetic tree.

The majority of the larvae were obtained locally and reared to the appropriate stages, and others were kindly given me by Prof. Heslop Harrison.

Dissections were made in Ringer's solution, Bouin's fixative, and in some cases in ordinary tap-water, all methods yielding good results.

After dissection, the testes were transferred at once to Bouin's fixative, in which they were left for at least twelve hours. They were then washed in 65 per cent. or 70 per cent. alcohol, brought by stages to absolute alcohol for dehydration, cleared in xylol and embedded in wax in the usual manner.

Sections were cut at a thickness of 6 μ and stained by the Heidenhain Iron—alum and Haematoxylin method.

Cytological Observations.

Family Papilionidae.

Papilio machaon L. Pupa dissected January 21st. Testes were separate. Chromosome number thirty, obtained from heterotype reduction division stages. (Fig. 1.)

Papilio podalirius L.

Dissections made on December 19th, a little earlier than in the case of *P. machaon*, gave the requisite stages, also from pupae. A haploid number of thirty was also obtained, and the chromosomes seem to be very slightly larger in size than in the preceding species. Kernewitz (1910) obtained the numbers 54-58 from spermatogonial counts in this insect, but in view of the clumping often observed at that stage, the discrepancy is probably not significant. (Fig. 2.)

Family Hylophilidae.

Halias prasinana L. Testes, apparently just fusing, were removed from a pupa on November 11th. The haploid chromosome number is thirty-two. The spindle is noticeably short, and faintly staining inclusions can often be observed. (Figs. 3-5.)

Family Caradrinidae.

Acronycta psi L.

Fused testes were obtained from pupae dissected on October 9th. The haploid chromosome number was thirty-one. This agrees with the determination made on a Russian race by Beliajeff 1930. Cytoplasmic inclusions during all stages have been figured. A detailed study of these structures is being made at the present time, and a paper on the subject is to be published as soon as the effects of non-acid fixatives have been tested. (Figs. 6-10.)

Ochria ochracea Hübn.

Two unfused testes were obtained from an early pupa on August 8th. A haploid chromosome number of thirty-one was indicated from counts made at the heterotype division stage. The chromosomes are somewhat ovoid. (Fig. 11.)

Family Selidosemidae.

Opisthograptis luteolata L.

The required stages were obtained from a pupa on February 12th when fused testes were present. The haploid chromosome number of thirty-one was again found. Moderately dark cytoplasmic inclusions were observed at different stages during the reduction divisions; also "chromatoid" bodies. (Figs. 12-15.)

Phigalia pedaria Fabr.

Fused testes were obtained in June from pupae. The number was unexpectedly high, one hundred and twelve chromosomes being counted as the haploid number. One of the chromosomes was larger than the others, and always retained its central position at the metaphase plate stage. (Fig. 17.)

Metrocampa margaritaria L.

Unpaired testes were obtained from larvae on May 30th. Thirty-one was the haploid number of chromosomes observed. (Fig. 16.)

Hygrochroa syringaria L.

Larvae dissected on June 20th. Testes unpaired. At the heterotype metaphase stage twenty-nine comparatively large chromosomes were counted. (Fig. 18.)

Selenia lunaria Schiff.

Unpaired testes were obtained from larvae on June 15th. The haploid number of chromosomes was thirty-one. (Fig. 19.)

Selenia bilunaria Esp.

Testes were mature, and unfused in larvae about June 20th. The haploid chromosome number was thirty. (Fig. 20.) Another race of the same species had a haploid number of twenty-nine. This was clearly a case of association, a large chromosome equivalent in size to two ordinary ones being observed in every plate, in this particular case.

Selenia tetralunaria Hufn.

Larvae of this species were dissected on June 24th-28th. Testes unpaired. The haploid number of chromosomes was twenty-nine. The chromosomes were larger than in previous species of Selenia examined. Faint inclusions were observed in the cytoplasm. (Fig. 21.)

Family Notodontidae.

Odontosia camelina L.

Fused testes were obtained from pupae on October 9th-10th. The haploid chromosome number was found to be thirty-one. Inclusions were present, which resembled somewhat those seen in Acronycta, but staining more faintly. This confirms a count made by Beliajeff (1930). (Fig. 22-24.)

Phalera bucephala L.

Suitable stages were encountered in the third week in December in fused testes obtained from pupae. At the heterotype metaphase stage thirty chromosomes were counted (Fig. 25). This is in agreement with the diploid number sixty obtained from spermatogonial counts by Kernewitz (1910).

Family Oecophoridae.

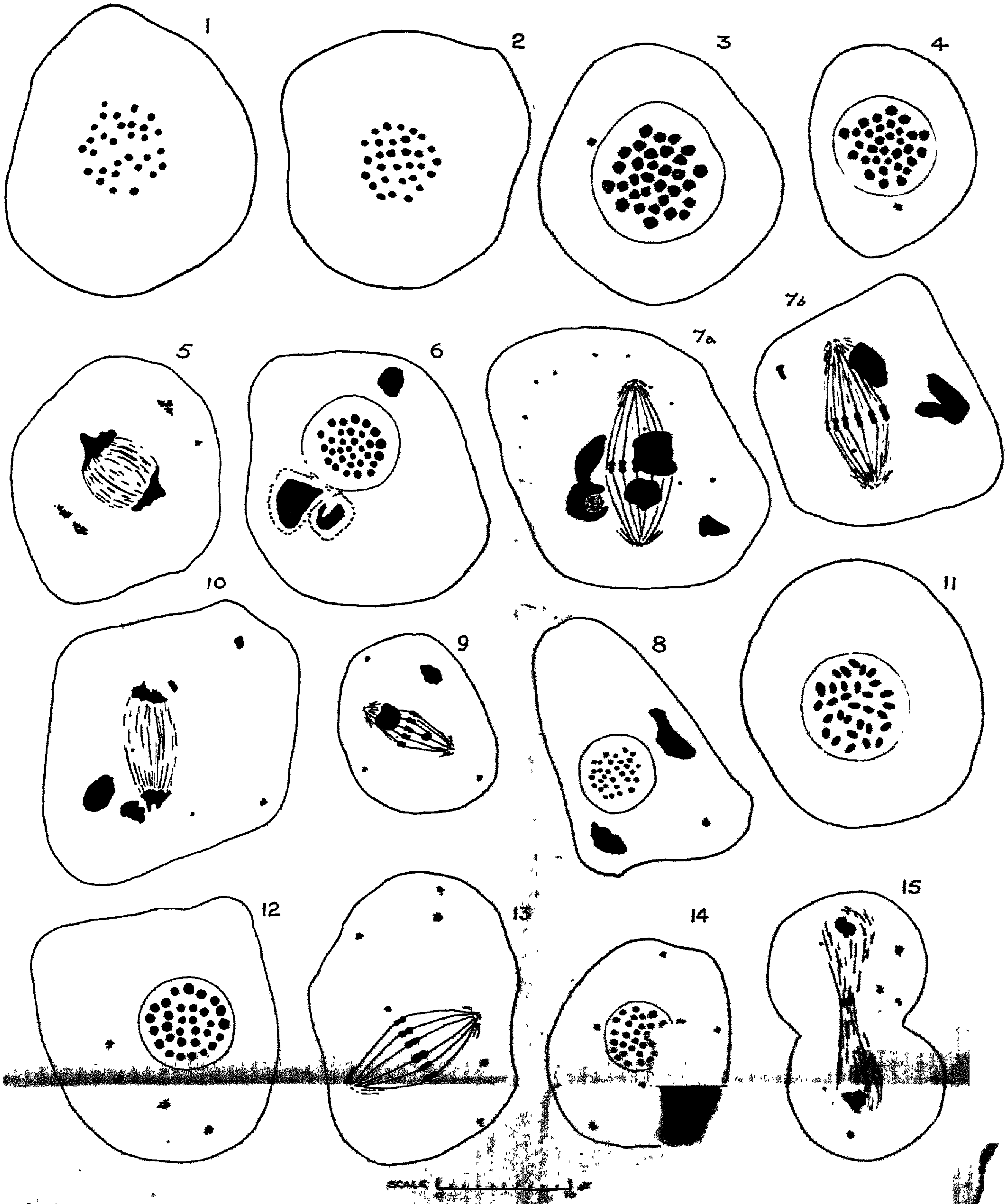
Depressaria nervosa Haw.

Fused testes, from pupae dissected on September 20th gave stages from which the haploid number thirty was obtained. The chromosomes were large. The nuclear membrane was faint at both the heterotype and homotype metaphase stages (Figs. 26-27).

Family Hyponomeutidae.

Hyponomeuta evonymella L.

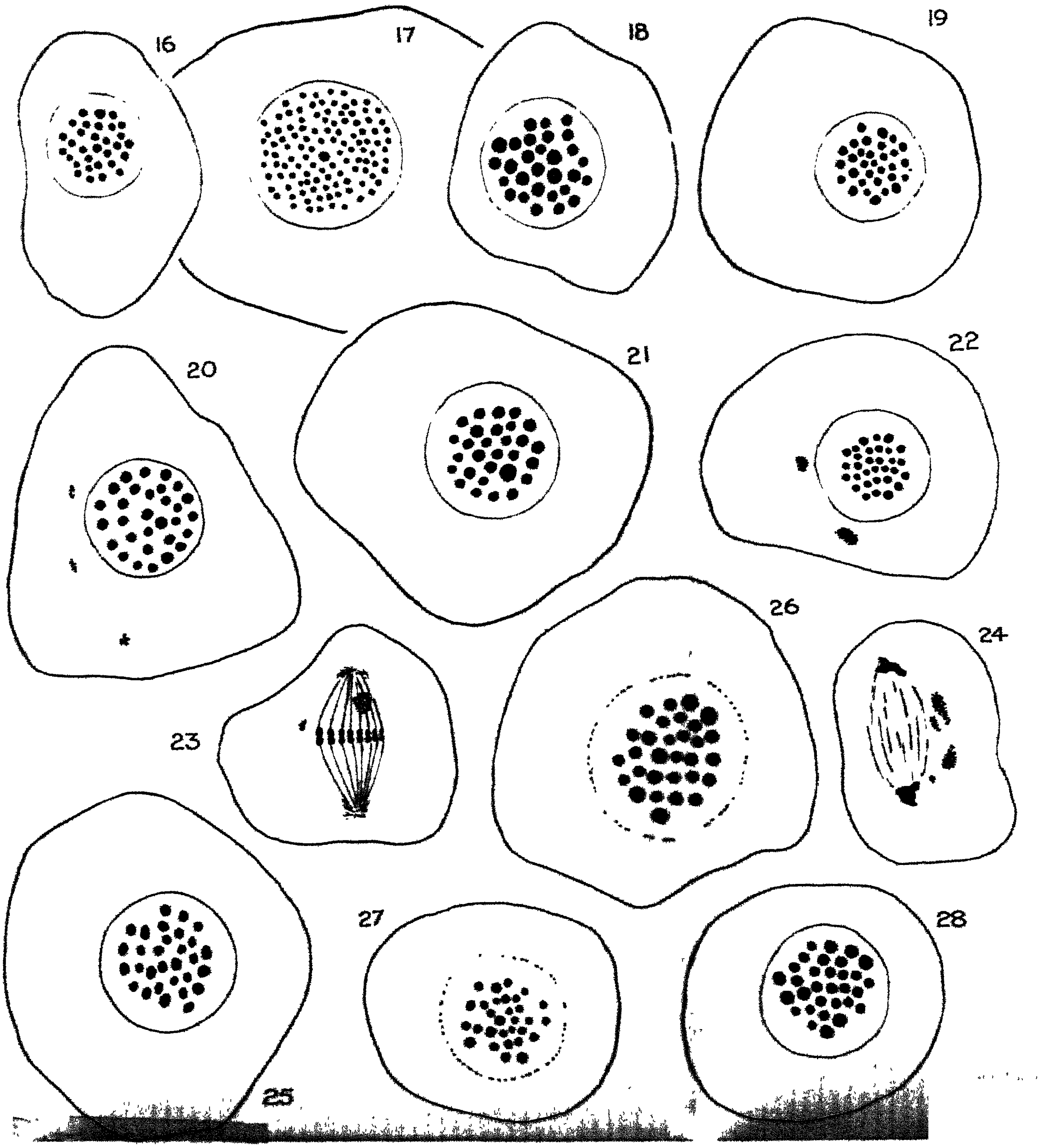
Suitable stages, which were obtained from pupae with fused testes on July 28th, showed that the haploid number was thirty-one, similar to that recorded by Beliajeff (1930). (Fig. 28.)



1 PAPILIO MACHAON HETEROTYPE METAPHASE PLATE.
2 " PODALIRIUS " "
3 HALIAS PRASINANA " "
4 " " HOMOTYPE METAPHASE PLATE
5 " " " TELOPHASE
6 ACRONYCTA PSI [illegible]
7a " " [illegible]
7b " " " " " "

8 ACRONYCTA PSI HOMOTYPE MET. PLATE & INCLUSIONS
9 " " PROF. VIEW SPINDLE AT HOMO. MET. & INCLUSIONS
10 " " HOMOTYPE TELOPHASE SHOWING INCLUSIONS
11 OCHRIA OCHRACEA HET. METAPHASE PLATE
12 OPISTHOGRAPTIS LUTEOLATA - & FAINT INCLUSIONS
" PROF. VIEW SPINDLE AT HET. MET. & FAINTLY STAINED INCLUSIONS
" HOMO. METAPHASE PLATE & INCLUSIONS.
HET TELOPHASE & INCLUSIONS

Drawings made with can



16 METROCAMPA MARGARITARIA HET MET PLATE
17 PHIGALIA PEDARIA " " "
18 HYGROCHROA SYRINGARIA HET. MET PLATE.
19 SELENIA LUNARIA " " "
20 " BILUNARIA " " "
21 " TETRALUNARIA " " "
22 ODONTOSIA CAMELINA HET. MET. PLATE & INCLUSIONS
23 ODONTOSIA CAMELINA PROF VIEW OF SPINDLE AT HET. MET STAGE & INCLUSIONS
24 " " HET TELOPHASE & INCLUSIONS
25 PHALERA BUCEPHALA HET MET. PLATE
26 DEPRESSARIA NERVOSA " " "
27 " " HOMOTYPE MET. PLATE
28 HYPONOMEUTA EVONYMELLA HET. MET. PLATE.

SCALE 0 10 μ

era lucida at a magnification of 4000.

The chromosome numbers obtained nearly approach the numbers thirty or thirty-one which are usually accepted as basal numbers for the order Lepidoptera. The chromosome complement of *Phigalia pedaria* is more unusual and is being studied in further detail at the present time.

I have to thank Prof. Heslop Harrison for assistance in obtaining some of the larvae and for giving me all facilities in the Department of Botany.

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NOTES ON THE CHROMOSOMES OF THE DUCKWEEDS (LEMNACEAE) INTRODUCING THE QUESTION OF CHROMOSOME SIZE.

By

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So much work has now been done on chromosome number and structure in the flowering plant, that it is tempting to try to take stock and analyse the results. With the idea of taking note of outstanding groups of plants, the family Lemnaceae has been examined because it consists throughout of very highly reduced and specialized aquatic plants. The duckweeds form a natural group, of very wide distribution, living in fresh water in all parts of both temperate and tropical regions. They are thought to be related, though distantly, to the Araceae, and of that family the tropical Water Lettuce, *Pistia,* is the nearest representative. All the members of the Lemnaceae have their vegetative body reduced to small flat fronds, with or without roots projecting from the under side. The fronds have been variously interpreted as stem, leaf, or part stem part leaf and, on these fronds, though rarely, much reduced inflorescences are produced in pockets near the base (1 & 7). The family is usually described as consisting of three genera, *Wolffia,* without roots, *Lemna,* with one root to each frond and *Spirodela,* with a bunch of roots beneath the frond. The genus *Lemna* is again subdivided, according to Engler (5) on a basis of the rare reproductive features thus:

Subgenus I Hydrophace.
    Section 1 Staurogeton. *Lemna trisulca* only.
    Section 2 Eulemna. *L. Minor*, *L. valdiviana* etc.
Subgenus II Telmatophace. *L. gibba* only.

In the five British species all the subdivisions of the family are represented: *Wolffia arrhiza* Wimm. our smallest flowering plant; *Spirodela polyrrhiza,* usually described in our floras as *Lemna polyrrhiza* L, the largest duckweed, the orbicular fronds of which measure up to 2/5 inch in diameter; *L. trisulca* L. differing from the others in having submerged fronds which remain attached to one another and only come up to the surface to flower; *L. minor* L. the common duckweed, the least specialized and the most worldwide in distribution, and, lastly, *L. gibba* L. which has a much thicker frond due to bulky air containing tissue below.

The interesting morphology has called forth many descriptive papers, but only the paper of Caldwell throws much light on the cytological detail. He describes the floral development of *L. minor* in great detail and even figures the reduction division but no attempt is made to draw the meiotic chromosomes in detail or to give their number. The present investigation is chiefly concerned with the somatic chromosomes as observed in the root tips. *Wolffia* presents great difficulties which are much increased by the entire lack of roots. In the absence of reduction divisions all that can be said with certainty is that *Wolffia* has a large number of somatic chromosomes ± (50) inextricably entangled at the metaphase and considerably larger than those to be described in detail below. The four British root bearing species considered in this account were all collected in the dykes of the Broads region of Norfolk, and were fixed on the spot by means of Langlet's modification of Navashin's Fluid. Local material of *L. minor* and *L. trisulca,* the only species which occur in Northumberland and Durham, has been examined for comparison.

The notable feature of the chromosomes of the whole group is their extremely small size. The drawings from which the figures were made are reduced in reproduction from a magnification of 6200 to one of 4000. An examination of the chromosome plates illustrated will at once reveal considerable differences between them. Considering first the question of number, *L. minor* and *Sp. polyrrhiza* each have 40 somatic chromosomes whereas *L. trisulca* has 44 and *L. gibba* 64. The occurrence of the number 40 twice is scarcely enough to establish it as the base number for the genus, although *L. minor*, being the least specialized, is probably nearer the primitive type (1). Examination of other species, particularly of the EULEMNA section, might be helpful in supporting such a hypothesis relating to chromosome number. The chromosomes of *L. minor* and *L. trisulca* approximate much more nearly in size among themselves than in the other species, which common feature, in itself, supports their position in the same subgenus but, on the other hand, their absolute size is very different, those of *L. trisulca* being extremely small. The occurrence of a large range of size within the complement might suggest an approach between *Sp. polyrrhiza* and *L. gibba*, but, again, there is an even more marked size difference, not to mention the conspicuous difference in number. The smallest chromosomes of them all occur in the former plant and measure apparently $\cdot 1\mu \chi \cdot 18\mu$ whereas the largest in the group, $\cdot 2\mu \chi 1 \cdot 4\mu$, are present in the latter. A consideration of these four complements can, I think, only point to the conclusion that the species examined are representatives of very divergent sections of the family, and only an examination of further species can give us a view of the whole group in its true perspective. No additional light is thrown on the relation of this family to Pistia by an examination of the chromosomes of the latter; although they are remarkably small the somatic number is 28. In size they are much more uniform than in the duckweeds proper.

The question of the extreme smallness of size of the chromosomes in duckweeds and particularly in *Spirodela polyrrhiza*, brings me to a point in which I have long been interested, that is the range of variation in the somatic chromosomes of the flowering plant. The more general aspects of this question were discussed in a previous paper delivered to this Society, but on this occasion I propose to discuss only the question of size.

Darlington, in his recent book (4 p. 85), has recorded various large and small chromosomes in both plant and animal worlds and perhaps the most striking case he mentions is that of the family Droseraceae recorded by Behre (2). *Drosera capensis* has very small chromosomes whereas *Drosophyllum lusitanicum* has very large ones. Presumably by measuring the rather small scale drawings, Darlington finds the dimensions of the former to be $\cdot 3\mu \times 1\cdot 9\mu$ and the latter to be $2\mu \times 25\mu$. It is of interest to note that the shape of the chromosomes is very different in the two plants. The relative bulk is calculated as in the proportion of $1 : 10^3$. This is a quite unusual range for a single family, and indeed *Drosophyllum* appears to have the largest chromosome on record, but Satô's measurements of the largest pair in *Lilium japonicum* and *L. speciosum* indicate that they are about this size (10). Darlington records *Hyacinthus orientalis* as running them very close with chromosome dimensions $2\mu \times \cdot 21\mu$. The largest type of chromosome of the set in *Haemanthus Kalbreyeri*, drawn in Fig. 6, is somewhat larger than the *Hyacinthus* for it is intermediate between it and *Drosophyllum* with its dimensions $2\mu \times 23\mu$. It is rather curious, though probably a mere matter of chance, that the largest chromosomes measured should all be so near the same size. The large family Caryophyllaceae has no chromosomes anything like this size. Its range of size is illustrated in Figs. 9 and 10 of *Cucubalus baccifer* and *Spergularia salina* respectively. The largest and smallest chromosomes here illustrated are $\cdot 7\mu \times 9\mu$ and $\cdot 1\mu \times \cdot 8\mu$.

Considering the small end of the range of size it is to be noted that the smallest Darlington has listed for the flowering plants is the *Drosera capensis*, $\cdot 3\mu \times 1\mu$, already mentioned, although he refers to *Saprolegnia mixta* as having chromosomes $\cdot 4\mu \times \cdot 4\mu$. The duckweed chromosomes are clearly much smaller and, as stated above, the smallest of all is estimated at $\cdot 1\mu \times \cdot 18\mu$ whereas the average size of chromosome of *Lemna trisulca* is no more than $\cdot 1\mu \times \cdot 5\mu$. There seems to be a general idea that things less than about ·25μ would not be visible but this appears, quite definitely, not to be the case. Elliot Merlin (8) has categorically stated that very much smaller particles can be seen, and it is calculated from his data that, with the conditions in use in the present work, particles as small as ·07μ should be distinctly visible by transmitted light. The question of resolution is the point at which difficulty arises. If the spaces between the chromosomes are greater than ·25μ then the number can be counted, if not, it cannot be done, as the images coalesce. Fortunately some of the plates in the Lemnas such as those figured, are well spaced and countable. Fig. 5 of *Scirpus maritimus* illustrates a plate of somatic chromosomes of a plant which has given great trouble in this respect. The chromosomes are all the same size and apparently spherical, but in most of the plates they are too close together to be resolved. The plate figured was completely resolved only under the most favourable conditions of optical equipment and lighting.[1]

A careful camera lucida drawing at a magnification of 6200 gave the average distance between the chromosomes as ·5μ and an estimate of the relative size of chromosome and space between, suggests that the chromosomes are about ·18μ in diameter. Other methods have been suggested for measuring very small objects as, for instance, the method of extinction described by Nelson (9) but so far the above method seems to have given the most reliable results. No attempt is being made here to consider anything but the apparent size, although it will be obvious, with a very little consideration, that errors due to optical effects are very large when dealing with objects of diameter less than the wave length of the light employed.

Considering next the volume of the chromosomes, it may be considered as a cylinder with hemispherical ends and the formula for calculating it becomes

$$\frac{\pi}{4} d^2 \left(l - \frac{d}{3}\right)$$

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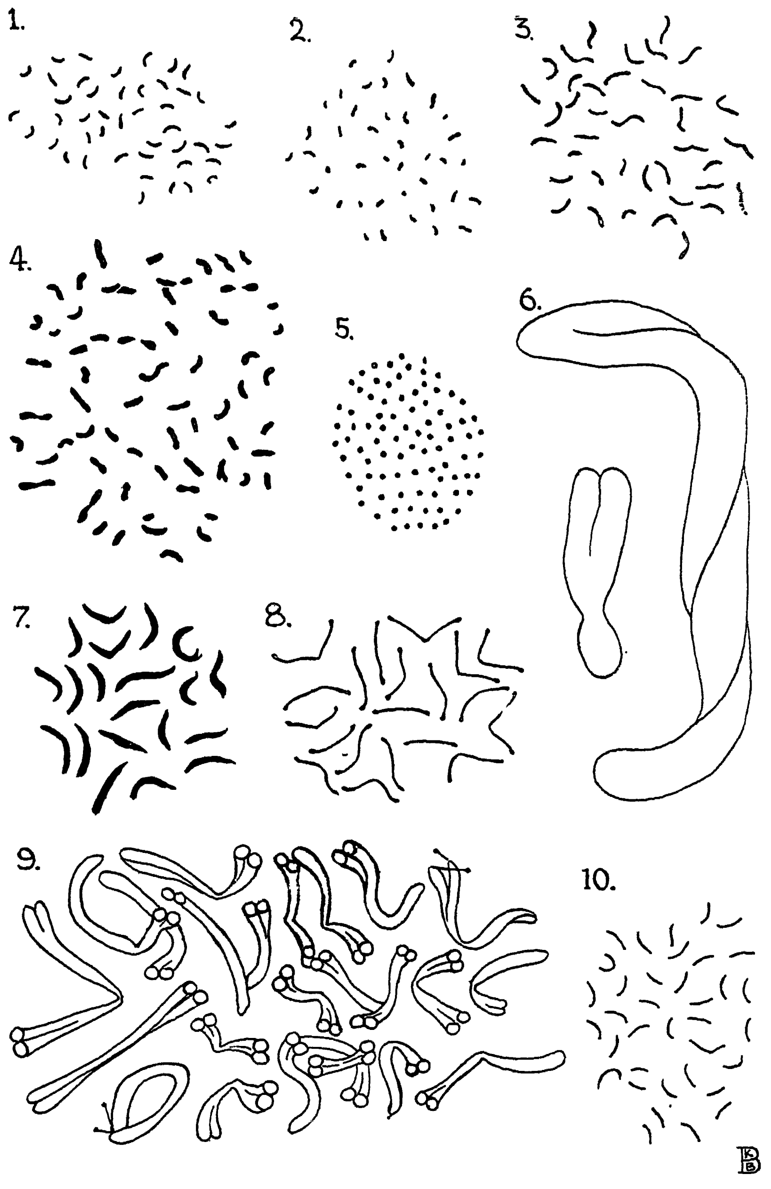
[1] A grant from the Royal Society for work on the Caryophyllaceae enabled the writer to have the use of a Zeiss 1.5 mm. Apochromat and compensating oculars and a pointolite as a source of illumination. A Watson Holoscopic immersion condenser and Wratten colour screens were also used for best results.



1. LEMNA TRISULCA 2. L. POLYRRHIZA 3. L. MINOR 4. L. GIBBA
5. SCIRPUS MARITIMUS 6. HAEMANTHUS KALBREYERI 7. & 8. HOLOSTEUM
LINIFLORUM 9. CUCUBALUS BACCIFER 10. SPERGULARIA SALINA. (×4000)

where d and l are measured length and width. On this basis the volume of the smallest chromosome of *L. polyrrhiza* is less than ·0012 cubic micron and that of *Drosophyllum lusitanicum* is 76 cubic microns. The approximate ratio between these two, 1 : 66,000, is very considerably greater than the range of 1 : 10^3 given by Darlington. It needs to be strongly emphasized here that anything but a round figure is useless, partly because of the considerable magnitude of the observational error referred to above, partly because a different fixative affects the size of the chromosomes,[2] and lastly because the actual size and shape is variable as between the different tissues and even sometimes in the same tissue, for no apparent reason. Figs. 7 and 8 are plates from a corresponding layer of one and the same root of *Spergularia salina*. Differences of this type have been recorded by Miss Harrison, though not in the same tissue, for *Euphorbia terracina* and the present writer has observed them equally noticeable in *Gentiana tibetica*. The cause of these exceptions to what is, after all, a general rule of similarity in corresponding cells treated in the same way, is still to be sought.

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[2] All the chromosomes figured on the plate were from material fixed with Langlet's modification of Navashin's fixative.

SUMMARY.

1. The chromosome numbers in the somatic tissues of the Lemnaceae are recorded as follows: *Lemna minor* and *Spirodela polyrrhiza* 40; *L. trisulca* 44; and *L. gibba* 64.
2. *Pista*, suggested as a near relation, has 28 somatic chromosomes about the same size as those of *L. minor*, but more uniform in size.
3. The chromosomes are all extremely small in Lemnaceae but considerable dissimilarity between the complements seems to indicate distant systematic divergence.

4. The range of size in Angiosperm chromosomes is discussed and the recorded range is extended at the small end, giving sizes from $2\mu \chi 25\mu$ to $\cdot 1\mu \chi \cdot 18\mu$; a range of 66,000 : 1 in volume.

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THE GREAT SULPHUR VEIN OF ALSTON MOOR.

By the late LLOYD M. THOMPSON, B.Sc. Arms.

Edited by Kingsley C. Dunham, Ph.D., B.Sc. Hatf.[1]

HISTORICAL INTRODUCTION.

The Great Sulphur Vein stretches along the slopes of the Cross Fell ridge from Burnhope Seat to the summit of Melmerby Fell, crossing in its course some of the wildest and most desolate fells of Alston Moor. It approaches within three miles of the summit of Cross Fell, and has a line of outcrop which only crosses the 1500′ contour line in the beds of streams, and is largely above the 2000′ line. The area traversed is almost entirely unenclosed moorland, heather covered, and buried under a varying thickness of peat.

The Sulphur Vein has for various reasons long been an object of interest to the inhabitants of the district. The staple occupations of the neighbourhood have always been farming, mainly sheep farming, and mining. Hence either as a shepherd tramping the fells, or as a miner seeking for ore, and frequently in both rôles, the local man has always been familiar with the vein. The great size and throw, conspicuous outcrop and peculiar nature of the vein—all in violent contrast to the well-known lead veins of the district—have combined to enhance the casual or calculating interest aroused.

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[1] L. M. Thompson, Research Student at Armstrong College from 1914 to 1915, lost his life in the Great War. His work on the Great Sulphur Vein was carried out during those years, and recorded in a thesis written in 1915. During a recent investigation of the North Pennine mineral province by the editor of this paper, Mr. Thompson's thesis came into his hands through the kindness of Dr. J. A. Smythe. It was felt that no comprehensive account of the Pennine ore deposits could be complete without some extended reference to Mr. Thompson's pioneer study of this vein unique among British occurrences; accordingly, the present paper was prepared to summarise his findings.

The vein was mainly remarkable to the local miner for the extraordinary masses of iron pyrites which it bore, and for the absence of the usual fluorspar-galena combination of the other veins of the district. It has therefore come to be known as the "Sulphur" vein, "Sulphur" being the miner's term for pyrite. A probably older name is the "Backbone," a term given evidently in recognition of its magnitude. One mining lease, evidently seeking after greater precision, went so far as to describe it as the "Backbone of the World."

While many writers on the mines of Alston Moor have described the Great Sulphur Vein, important contributions have been made by three only; Westgarth Forster (1809), William Wallace (1863) and C. E. De Rance (1873). Forster was the first to mention the vein, and believed it to be identical with "the vein that crosses the River Eden at Armathwaite Bay," and also with the Slitt vein of Weardale. The mapping of the area by H. M. Geological Survey showed that its extent is not really so great as Forster supposed. Wallace's account was the most comprehensive of the early works on the vein, and from it all later authors have drawn their information. Wallace conceived of the fracturing as due to anticlinal folding, and the filling as due to concentration by the circulating groundwaters. De Rance added some details concerning the Tynehead district to Wallace's description. The textbook of J. A. Phillips and H. Louis (1896), contains a summary of the information available in the literature up to the time of its publication.

From a commercial point of view, this huge vein has never yielded anything of value. Trials have repeatedly been made upon it, by means of surface excavations, and by levels driven in from the valley bottoms, and in at least two localities, attempts have been made to work it for gold. All these endeavours have been unsuccessful, and the vein remains to-day a melancholy example of a deposit most attractive to the prospector but most disappointing to the would-be operator. It merits, however, some attention from a scientific point of view.

TABLE I.

SUMMARY OF EXPOSURES OF THE GREAT SULPHUR VEIN.

Locality.	Throw (in feet)	Width (in feet)	Mineralogy.
Darngill Bridge ...	Series of	small faults	Q., tr. Cp.
Sidehead Sike level ...		168	Q., Po.
Sir John's level ...	150 N.	112	Q., Py., Cp. G.
River South Tyne ...	150 N.	270	Q., Py., Po. G.
Dorthgill	120 N.	270	Q.
Noonstones	120 N.	1200	Q.
Crossgill	130 N.		Q., Py.
Duffergill			Q.
Stannersgill		440	Q.
Cashburn	600 N.	120	Obscured.
Blackburn		108	Q., Py.
Swarth Beck	250 N.	150	
Smittergill	250 N.	150	Q., Py., Po.
Aglionby Beck Head ...	small		Q., L.
Knapside branch ...	150 N.		Q.,Py.,G., Pm.
Melmerby Fell top ...	0		Q.

Symbols: N, north; Q, quartz; Py, pyrite; Po, pyrrhotite; Cp, chalcopyrite; G, galena; L, limonite; Pm, pyromorphite.

GEOLOGY OF THE DISTRICT.

Sediments of Lower Carboniferous age (Carboniferous Limestone and Yoredale Series) form the country rock of the vein, and the vein-fracture can be seen traversing beds from the Melmerby Scar limestone horizon on the Eascarpment, to the Great limestone on Noonstones Hill. The sediments consist of an alternating series of limestones, sandstones and shales, with minor coal seams. There are roughly equal thicknesses of the three first-mentioned components in the part of the Lower Carboniferous series cut by the vein. The sediments are tilted gently towards the north-east.

Igneous rocks in the area are limited to two intrusives of widely different ages. The Great Whin sill, a sheet of quartz dolerite of wide extent, was intruded prior to the vein, by which it is faulted. Waterfalls sometimes occur where the vein has faulted the hard rock of the sill. The Cleveland-Armathwaite dyke of Tertiary age, a tholeiite in composition, runs parallel to the vein at a distance of about one half-mile on the south side.

VEIN STRUCTURE.

The vein is well exposed at the surface throughout most of its course; indeed, its quartzose matrix has caused it to form a prominent surface feature. Not only is it to be seen in the beds of the streams which cross it, but also on the slopes, and sometimes even on the flat tops of the hills. The accompanying table (page 93) summarises the evidence regarding width and displacement of the vein which was afforded by detailed mapping. Except in a few cases, further discussion of individual exposures is unnecessary here; some general observations upon the structure may, however, be recorded. The dislocation which has formed the basis of the vein extends in a general east-west direction from the summit of Burnhope Seat to the ridge of Melmerby Fell, a distance of 8½ miles. Rather less than ¾ miles from the western termination, a vein which displaces the strata to a considerable extent is given off to the south-west. This vein may be regarded as the tectonic continuation westward of the main vein, for dislocation has taken place along its line rather than along the direct westward continuation of the vein proper. The maximum displacement of the Sulphur vein occurs in the central part of its course, at Cashburn. Eastward and westward from this exposure the magnitude of the faulting decreases. The eastern termination, which can be seen on Yad Moss near the Alston-Middleton in Teesdale road is complex owing to the fact that the vein is here dying out in a series of divergent faults of small magnitude. The faulting throughout the vein is of the "normal" type, for the fracture system dips steeply to the north, in the direction of the downthrow side.

In its simplest form the vein consists of two filled fractures enclosing between them a strip of the country rock; but usually there are many mineralised fissures. The great width which is attained (the maximum is 1200′) must not, therefore, be regarded as consisting wholly of vein-filling; much of this width is made up of included slabs of country rock. When large masses of sedimentary material in which the bedding can be recognised are enclosed between the bounding fractures it is seen that they have a steep northerly dip. The greater part of the dislocation seems to have been taken by the southernmost fracture in the instances in which the relations are clear.

The Sir John's mine, in which a level was driven through the Sulphur vein, is of special interest because it indicates the structural relationship of the Great Sulphur vein with the normal lead veins of the district. The Sir John's vein, running NW-SE, was followed south-east to its intersection with the Sulphur vein, which was found to be 112′ wide and to contain 24′ of pyrite. All observers agree that all trace of the Sir John's vein was lost in the Sulphur vein, but on the south side it was again discovered, shifted 20 fathoms out of its course. Its mineral content was identical in every respect with that on the north side of the intersection. It is therefore concluded that the Sulphur vein is younger than at least one representative of the normal veins of the district.

MINERALOGICAL FEATURES.

The major constituents of the vein are quartz and pyrite. In addition, pyrrhotite, chalcopyrite and traces of galena occur. There is a notable contrast between the mineralogy of this vein and the galena-sphalerite-fluorspar-barytes assemblage which characterises the normal lead veins of Alston Moor.

The quartz is coarsely crystalline, and is present in great quantity. (An estimate of the quantity of this constituent alone in the first hundred feet of the vein gave the figure of 15,000,000 tons.) It is unlike the typical quartz of the lead veins, which is generally fine grained. Inclusions in the crystals are numerous and to this cause the milky white colour of the mineral is attributed. The inclusions are generally orientated in lines parallel to the rhombohedral faces, and in most cases consist of minute cavities containing liquid in quantity now insufficient to fill the cavity-space. Application of the method devised by H. C. Sorby (1858) for calculating the temperature of formation of the quartz from the relative size of cavity and bubble gave as a result 181°C. The assumption is here made that the liquid is pure water, and that the pressure under which the quartz was formed was that of aqueous vapour. As, however, the pressure was probably much greater, the temperature must have been correspondingly greater, and the figure quoted must be regarded as the minimum possible value.

The pyrite is intergrown with the quartz in a curious manner. The sulphide occurs in plates with parallel sides, and the plates stand in various relations to one another. Sometimes a crude radiation of the plates from a centre is shown. The cause of this habit of the pyrite is not known, but it clearly represents an original intergrowth with the quartz.

An assay of the pyrite from Sir John's mine showed no gold.

Both in time and in space, quartz has been more persistent than pyrite, for there is a general tendency for a pure quartz phase to succeed the pyrite-quartz intergrowth. Pyrite is further confined to the lower parts of the vein, and, indeed, is not found above the present 1500' contour; while the upper part of the vein is composed entirely of quartz. Thus the minerals of the vein show a simple zonal relationship, pyrite being found where the valleys have cut down into the deeper levels, and quartz alone making up the vein stuff on the slopes of the hills. It is evident at once that pyrite has never been present in the upper parts of the vein. The quartz is white and massive, and there is no gossan, save only at Aglionby Beck Head, where a limonitic outcrop of the vein in contact with much altered Whin sill was formerly worked for umber.

All sediments occurring in and near the vein have been silicified. Limestone shows this feature conspicuously, and a Lithostrotion coral was found pseudomorphously preserved in silica. Sandstones show secondary quartz deposited on their grains, and argillaceous rocks also show the presence of infiltrated silica. The Whin sill rock has been decomposed to form a characteristic "white trap" against the vein.

AGE AND ORE-GENESIS.

The coarsely crystalline nature of the quartz, the presence of pyrrhotite, and the testimony of the liquid inclusions in the quartz combine to indicate that the mineralisation of the Great Sulphur Vein was due to hot solutions. The presence of iron di-sulphide as pyrite rather than as marcasite indicates, according to the work of Allen, Crenshaw *et aliter* (1912) that the vein solutions were dominantly alkaline in character. The possibility that alkali sulphides were present is worthy of consideration, for in these the silica and iron sulphide would be relatively soluble. While it is thought that the nature of the vein and the solutions concerned with it indicate a direct igneous origin, this point is not pressed, as the possibility remains that waters deriving their heat from igneous intrusions might have leached from the rocks they traversed their content of silica and possibly sulphide.

But it is insisted that the heat was supplied by igneous intrusions; the localisation of the peculiar Sulphur Vein phenomena forbid appeal to anything but a local cause.

Of the age of the vein, the only certain evidence is that it is post-Lower Carboniferous, and later than one representative of the Alston Moor mineral veins, the Sir John's vein. If the lead veins of the Alston Moor field are all of the same age, then their age is certainly pre-Tertiary, since the Cleveland dyke cuts a representative of this group near Tynehead (Phillips and Louis, 1893). The parallism of the Great Sulphur vein with the Cleveland dyke suggests that it may have been formed by the same regional stresses, and may belong in a general way to the same period of igneous activity. No definite pronouncement upon this subject is, however, possible until more conclusive evidence is forthcoming.

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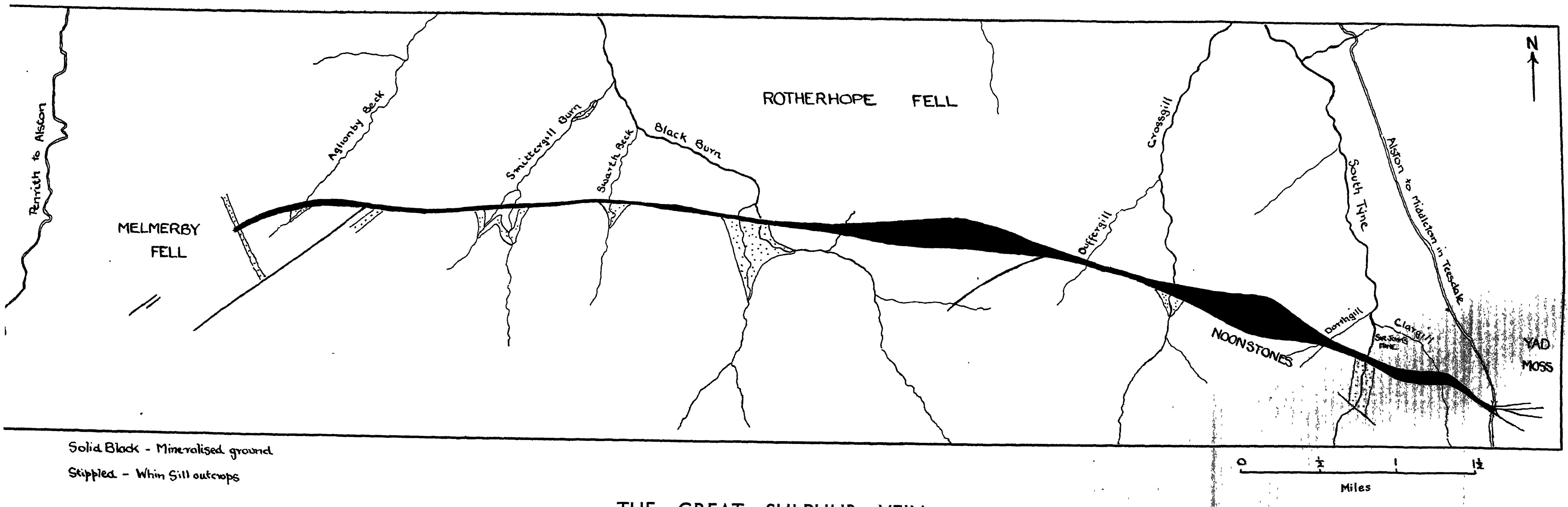


THE GREAT SULPHUR VEIN

from a Six-Inch Map by L. M. THOMPSON.

AN EXAMINATION OF ROMAN COPPER FROM WIGTOWNSHIRE AND NORTH WALES.

BY

G. CLEMENT WHITTICK, M.A., and
J. A. SMYTHE, Ph.D., D.Sc.

Among the objects of Roman origin from sites in Scotland recently catalogued by Dr. James Curle was included a cake of copper from Carleton, Glasserton, Wigtownshire,[1] with the suggestion that it perhaps represented a link with the copper-mining area of Wales. An inquiry by Dr. Curle as to the possibility of establishing this, either by similarity of dating or by examination of the metal, led me to procure specimens from the Carleton cake and also from four cakes found in North Wales and now in the British Museum.[2] The latter are as follows:

A. *C.I.L.* vii. 1199. Found near Amlwch, Anglesey.
B. Found near Amlwch, Anglesey.
C. *Eph. Epigr.* ix. 1258. Found on the south slope of Carnedd Llewellyn, Carnarvon.
D. *ibid.* 1259. Found near Capel Curig, Snowdon.

Metallurgical details of these and of the Carleton specimen are set out below by Dr. Smythe.

First arises the question of relative dating. The Carleton copper was ploughed up circ. 1880, and is "like a thick cake, irregularly circular, 9 inches in diameter, 3 inches thick, weighing about 36 lb. It appears to have been cast in a rude open mould or pan with edges expanding slightly outwards and upwards." The Roman origin of this mass, while not proved beyond all possibility of dispute, can hardly be doubted, in view of its close correspondence in general shape and dimensions with the numerous cakes from the North Wales area, where the average diameter is about a foot, the thickness about 2 or 2½ inches, and the weights vary between 30 and 50 lb. Considered in isolation, the cake cannot be more closely dated, and no associated finds are recorded. As Dr. Curle's list shows, however, the other discoveries in this south-west part of Scotland indicate Roman penetration from the south at the end of the first or the beginning of the second century. It would seem therefore reasonable to attribute the Carleton copper to the same period.

Turning to the North Wales examples, we find that here also no direct evidence for dating is available. No dateable objects are recorded in association with any of the cakes: and though several bear some kind of inscription, no full interpretation of them has yet been offered. On the other hand, the letters IVLS and IVLI visible on the two cakes found near Amlwch (Anglesey), and on another found on the shore not far from Criccieth (Carnavon)—probably all from the Parys Mines in Anglesey—may indicate a Julius as controller or lessee of the copper mines in this area, while the well-known example found near Aberfraw in Anglesey in the seventeenth century and stamped SOCIO ROMAE also suggests a mining-partner (*socius*) or a mining-company (*societas*) of the Romans. Such leasing-out of mining-rights is well established in the Roman period, though the evidence for it in Britain is slight and is elsewhere restricted to lead-mining, where however it can be dated to the second half of the first century.[3] If, as seems probable, a similar practice was followed in the North Wales copper district, then it is arguable that it dates to approximately the same time: and mining activity here in the last quarter of the first and the early years of the second century would accord well with our knowledge of the Roman occupation of North Wales.

It is suggested, therefore, that the Carleton copper and the North Wales copper belong in all probability to the same period. For the establishment of any closer connection between them we must look to the metallurgical examination of the specimens. For my own purpose it will be sufficient to point out here that while an important distinction not otherwise evident has been established, namely, that the Carleton cake is not the result of a smelting operation, as are the other four, but is a prepared alloy, determination of the nature of the copper used, and its comparison with the North Wales coppers, gives strong support to the suggestion that it derived originally from that particular area. In view of this, the shape and dimensions of the Carleton cake become of particular interest. Copper alloys have been found not infrequently elsewhere, but always in irregular masses,[4] never cast in the "shallow pan" type of mould, which is characteristic of the North Wales products.

G. C. W.

Chemical and Metallurgical examination of the metals.

The samples supplied by the British Museum were in the form of filings and fine drillings, containing apparently dirt and scale from the outside of the cakes. A and B yielded some metallic iron to a strong magnet, and the fine powder showed under the microscope fragments of a dark cubic mineral, with a light brownish streak, which appeared to be cuprous oxide. All were washed thoroughly in running water, then with hot alcohol and quickly dried.

The analytical results confirm the conclusions drawn from the microscopic examination that the samples are contaminated with dirt and scale. The iron is probably present as oxide, since in one sample it was found to be soluble in dilute hydrochloric acid. The matter insoluble in acid was gritty and siliceous and there is a notable amount of lime, estimated as oxide, but present as carbonate along with a trace of magnesia. All of these constituents are derived from the scale. This would also probably carry some cuprous oxide and the low totals in

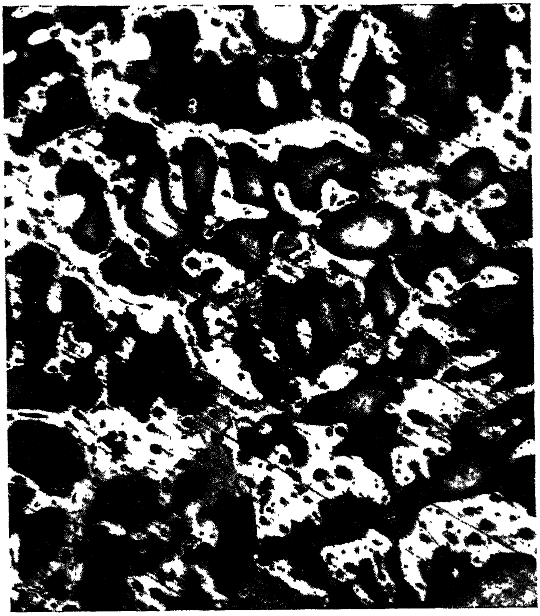
A and B may be ascribed in part to this. The metal itself in all cases is of a high degree of purity and contains mere traces, or little more, of silver, tin, arsenic, nickel, zinc and (in the one case in which the quantity sufficed for a determination) of sulphur. Such a metal could only be produced by the skilful smelting of pure oxidised ores, probably carefully selected.

The analyses are:

	A	B	C	D
Copper	98·90	99·08	99·00	99·08
Silver	tr.	none	0·03	0·03
Tin	tr.	none	none	none
Arsenic	0·03	tr.	0·06	tr.
Iron	0·11	0·04	0·09	0·10
Nickel	0·02	0·01	0·02	0·02
Zinc	tr.	tr.	tr.	tr.
Sulphur	n.d.	0·04	n.d.	n.d
Insoluble	0·35	0·07	0·18	0·13
Calcium Carbonate ...	n.d.	0·39	0·73	0·41
TOTALS ...	99·41	99·63	100·11	99·77
S.G.	8·56	8·65	8·73	8·52

I am indebted to Mr. D. Burn, M.Sc., of the Bede Metal and Chemical Co., Hebburn, for his kindness in determining the arsenic in A and C and for checking by a different analytical method from the one used by me, the copper determinations in the same two samples.

The metal from the National Museum of Scotland was supplied in the form of a substantial piece sawn from the cake, and coated on the outside with a thin film of corrosion-product. It was thus possible to study its microstructure, a photomicrograph of which is reproduced below. This shows a strongly cored bronze-like metal, without eutectoid patches and consequently poor in tin. It contains, as will be seen, a relatively large quantity



Photomicrograph of the Carleton alloy × 45 diameters.

Showing cast structure—heavy coring of the alpha solid solution, eutectoid being absent. The lead is distributed fairly uniformly in the form of small globules, some preference for the grain-boundaries being apparent.

J.A.S.

of lead, distributed in the form of small globules. Analysis of the metal gave:

Copper	93·04
Silver	0·14
Lead	4·87
Tin	1·85
Arsenic	tr.
Antimony	tr.
Iron	0·13
Zinc	none
Nickel	0·10
Sulphur	0·02
	100·15
S.G.	8·81

The analysis[5] thus agrees with the metallographic appearance of the metal as essentially a leaded alpha-bronze. A metal of this composition and structure can hardly be a smelting product. It is rather a prepared alloy and the uniform distribution of the lead throughout indicates that the molten alloy was well stirred just before casting. This has clearly been done with intention. The Romans frequently used leaded bronzes for the making of all kinds of objects and they were evidently well aware that the addition of lead to bronze facilitated the casting and working of the metal and improved the patina which was developed later.

One is therefore justified in regarding this metal as an alloy prepared from copper. The composition of the copper used can be determined by recalculating the analytical figures on the basis of metal free from lead, tin and iron (as the iron-content is rather too high for a copper of good grade, it is likely to have been picked up in later operations). The results of this are given below in column 1, and, for comparison, the mean values for the four coppers A and D, calculated on the basis of material free from scale and dirt, in column 2.

	1.	2.
Copper	99·72	99·91
Silver	0·15	0·01
Arsenic	tr.	0·02
Nickel	0·11	0·02
Sulphur	0·02	0·04
	100·00	100·00

The composition of the copper in the Carleton alloy (No. 1) is thus so similar to that of the four Welsh coppers (No. 2) that identity of origin appears extremely probable, and the evidence from the chemical examination of the materials thus reinforces the conclusions arrived at in the first part of this paper. A simple calculation shows that the addition of two parts by weight of tin and five of lead to one hundred parts of the Welsh copper would yield a product identical in composition, within the limits of experimental error, with the Carleton alloy.

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[2] I am indebted to Dr. Graham Callander, Director of the National Museum of Scotland, for the Carleton specimen: and for drillings from the British Museum cakes to Mr. Reginald A. Smith, Keeper of the Department of British and Mediæval Antiquities.

[3] Pig of lead from the Mendips (found at Bitterne, Southampton, in 1918) with lettering (incised) SOC NOVEG. Derbyshire should also, in my view, be added. I regard the non-imperial *Lutudarum* examples as pre-Hadrianic.

[4] For good examples see those examined by Gowland from Hengistbury Head, Hants. (*Soc. Ant. Res. Comm. Rep.*, iii, pp. 72, 73.)

[5] The following analysis, differing widely from the above, is preserved in the Library of the Soc. of Antiq. of Scotland: Copper, 96·764; zinc, 1·914; insoluble siliceous matter, 1·322; total, 100·000: cf. Curle, *loc. cit.*

THE PRESERVATION OF PLANT TISSUES IN COAL.

Prof. H. G. A. Hickling, D.Sc., F.G.S.,
and C. E. Marshall, B.Sc.

Recent improvements in the preparation of thin sections have made it possible to demonstrate the details of plant-structures in coal more fully than has hitherto been done, even in the excellent descriptions by Thiessen, Seyler, Duparque and others.[1] Such structures are most perfectly preserved in the brilliant glassy form of coal known as vitrain (Anthraxylon of Thiessen), though they are often more obvious in the "mineral charcoal" or fusain. Certainly all vitrains do not retain their original structures equally well; some indeed approach an almost uniformly structureless condition with but vague indications of their original form. On the contrary, the excellence of the detail preserved in other samples is truly amazing. The authors have recently been fortunate in obtaining some very fine specimens of vitrain which seem to throw some light upon this mode of preservation. For the purpose of completeness and comparison a very brief description of fusain is included.

Fusain, apparently derived in all cases from thick walled tissue, is composed of highly opaque material[2] which forms the cell walls and encloses the empty or mineral-infilled cell cavities (Fig. 1a). When crushed, it does not yield by distortion of the cell walls, but by actual fracture, the fragments being sharp and angular ("bogen—struktur") and suggesting a very brittle nature (Fig. 1b).

Vitrain is almost entirely derived from wood and bark fragments. A description of a vitrain derived from a Gymnospermous wood has already been published (Hickling and Marshall. " The Microstructure of the Coal in

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(1), (2) See page 115.

Certain Fossil Trees." Trans. Inst. Min. Eng., lxxxiv., 1932, p. 13) so it will suffice here to give only a brief account. A preliminary examination of the transverse section of the wood vitrain shows a darker ground traversed by narrow, more or less distorted and apparently continuous parallel light bands. Closer examination reveals that these pale bands are, in fact, discontinuous

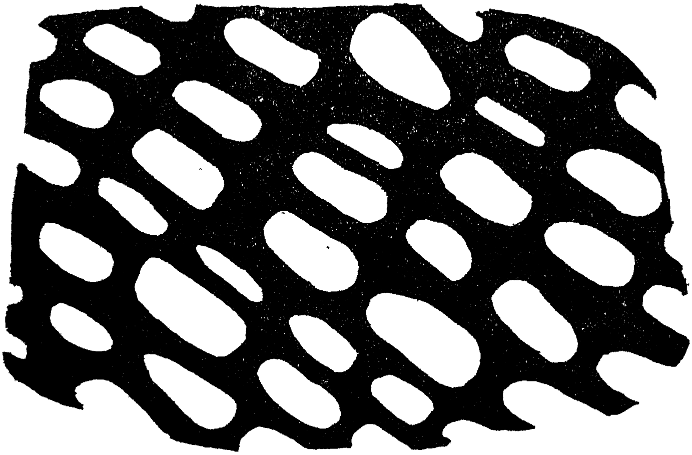

FIG. 1A.

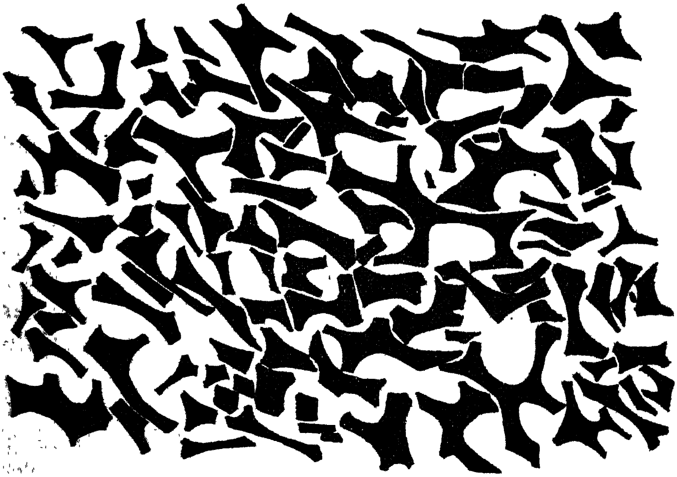

FIG. 1B.

and the structure is resolved as shown in Fig. 2. The darker ground is formed by the closely packed walls of the wood fibres (Fig. 2, —w). In the fibre walls, small angular dots occur at fairly regular intervals and from these dots, faint and paler streaks can be traced extending medially through the walls; these latter are the middle lamellæ (ml) and the dots represent the intercellular spaces. The sinuous pale strips (1) are the remains of the cavities of the wood fibres. These cavities were originally rectangular in cross section and large in proportion to the wall thickness but are now reduced to a fine band and distinguished only by their slight infilling with a pale coal substance. Between the twisted ends of these reduced cell cavities are shorter bars which, when the evidence of vertical sections is taken into account, can be readily interpreted as representing the pits in the cell walls of the wood fibres.

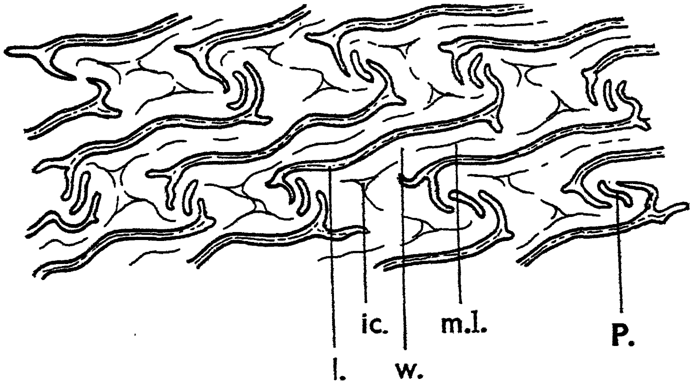

FIG. 2.

In no single instance has it been possible to detect the slightest indication of fracturing of the cell-structures in a vitrain. The impression given is that of the crushing of a plastic mass which has yielded uniformly, thus providing a marked contrast with the behaviour of fusain under stress.

Traversing the wood tissue are numerous broader bands infilled by a paler coal material. These are the medullary rays. Though crumpled by contact with the relatively hard wood fibres, their component cells are not compressed or flattened to any extent. The excellent preservation of this thin walled ray tissue is even more strikingly shown in tangential and radial sections. In the former, the rays appear as chains of light coloured oval cells (Fig. 3), and in the latter as plates of pale

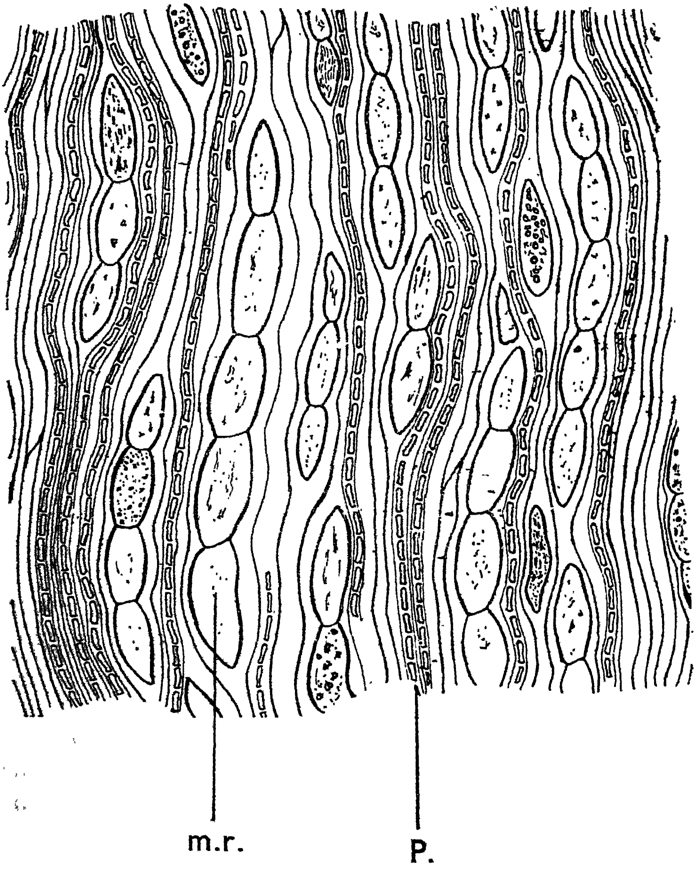

FIG. 3.

coloured brick-shaped cells whose thin cell walls appear as fine rims to the resinous-looking cell contents. In each and every instance they remain quite uncrushed whilst the much thicker-walled wood fibres lying between the rays are almost completely closed. In both tangential and radial sections the pits are also exceedingly well preserved, the radial section exhibiting them as characteristic crossed bordered pits of uniserial habit, and the tangential sections as delicate links of pale coal substance forming numerous fine chains. In addition to the medullary rays, part of thin-walled pith of the stems is very well preserved, whilst the surrounding wood tissue is highly crushed.

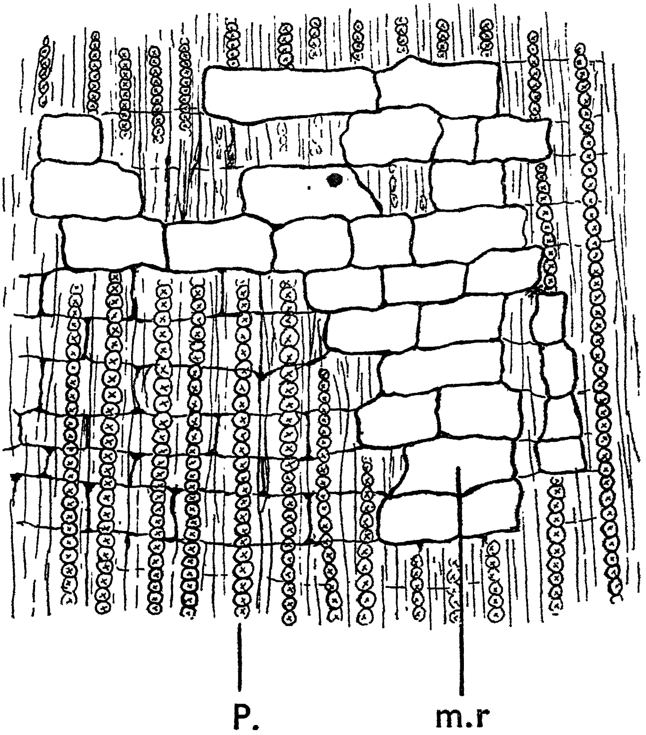

FIG. 4.

Vitrains derived from bark tissues exhibit a similar state of affairs. The thin-walled tissue with the infilling of coal substance is often beautifully preserved whilst the strands of schlerenchymatous tissue are greatly compressed and the cell cavities almost obliterated. This is well illustrated in Figs. 5a and 5b. In Fig. 5a the dark, continuous line which at first sight appears to be the cell wall, is found on closer examination to be the middle lamella (ml); the cell cavities (1) are almost completely closed and in conjunction with the middle lamella, show obvious signs of crumpling. This prominence of the middle lamella appears to be a common feature of bark tissues preserved as vitrain and so far it has been found to be invariably more marked in the radial than in the tangential walls. Fig. 5b indicates the excellent and relatively uncontorted state of the thinner-walled tissue.

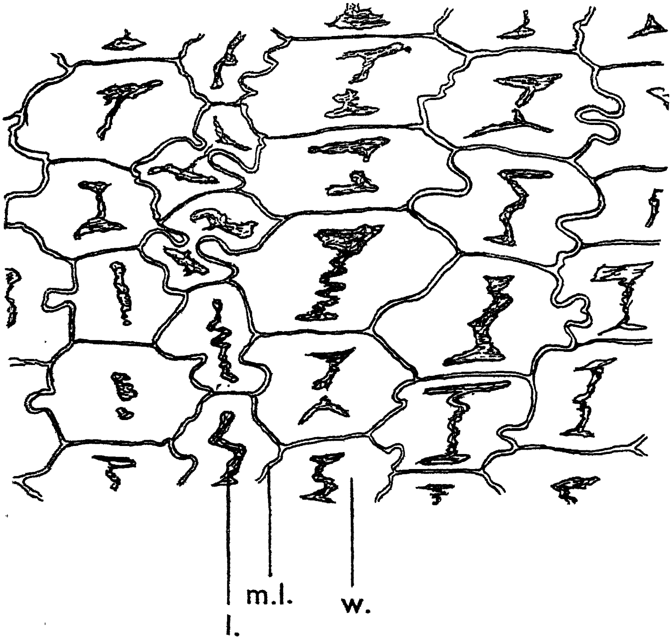

FIG. 5A.

The cell infilling in this instance is a relatively dark coal substance. In contrast with the last figure, another instance of the crushing of thick-walled tissue is shown in Fig. 6.

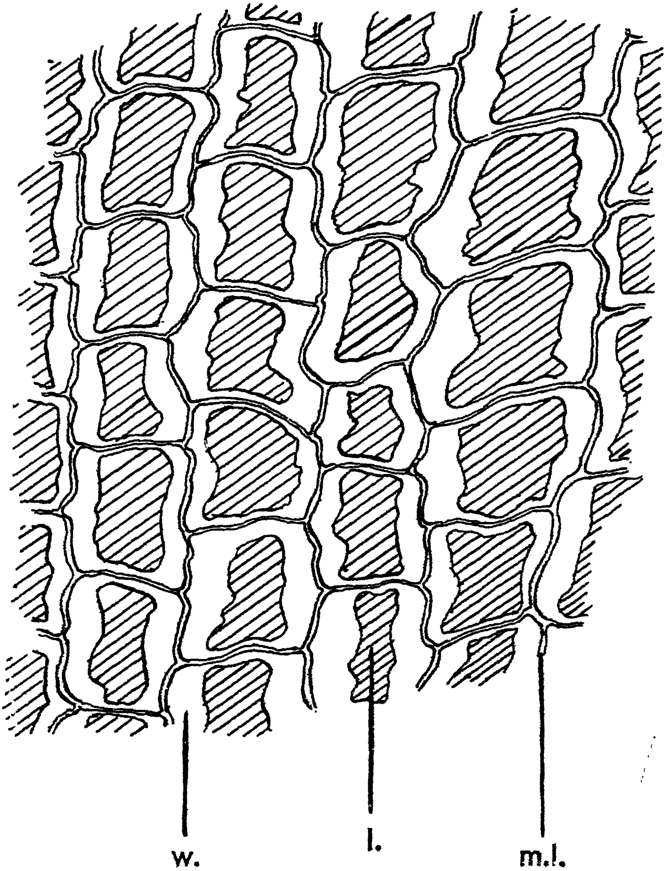

FIG. 5B.

This brief synopsis demonstrates the unexpected fact that a tissue originally mechanically weak (medullary rays, pith, the less thick-walled cells in barks, etc.) has survived conditions of stress which have completely crushed the originally stronger wood. The obvious explanation of this lies in the filling of the thin-walled cells by organic fluids to which the thick walled tissue was presumably impenetrable. The infilled cells would resist like a solid block while the empty thick-walled cells would collapse.

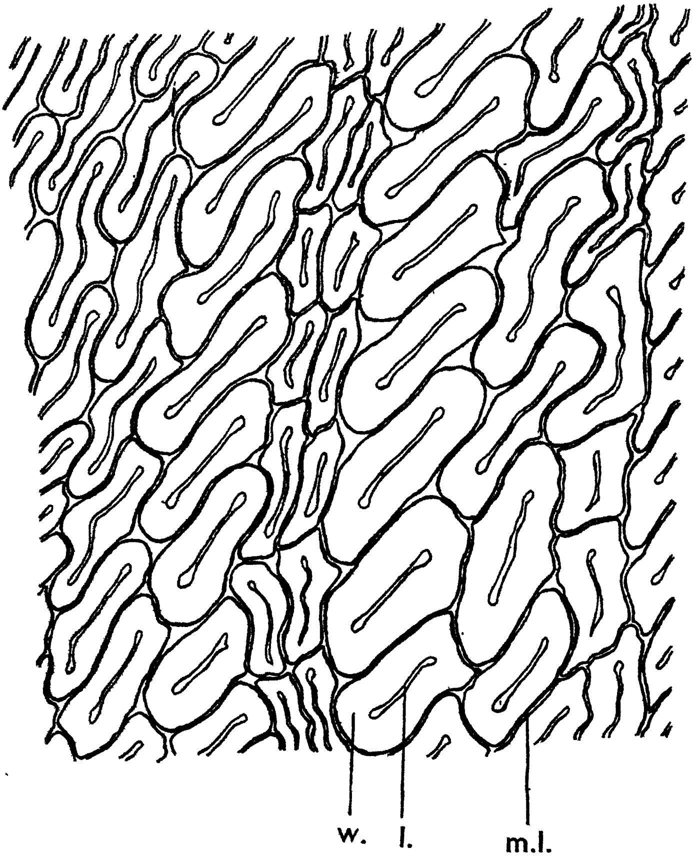

Fig. 6.

Evidence which appears to demonstrate conclusively the occurrence of such infilling of thin-walled tissue has recently come to light in a bark of Bothrodendron (see figs. 7a—d). In this tissue each of the cells appears to be divided by a fine median septum (see fig. 7c) in the radial plane. Closer examination reveals that the septum in all cases expands at either end, where it seems to adhere firmly to the tangential walls of the cells. In some cases the tangential walls have the appearance of having been pulled in by the septum. Further examination reveals many cases in which the septum is not a mere

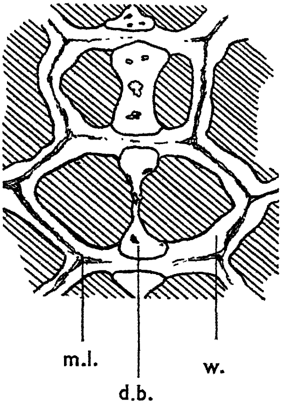

FIG. 7A.

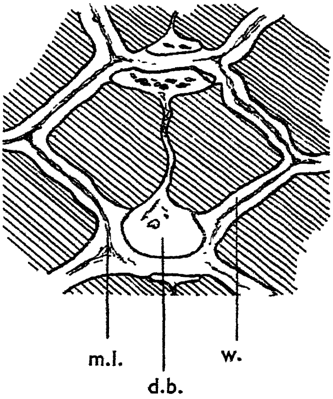

FIG. 7B.

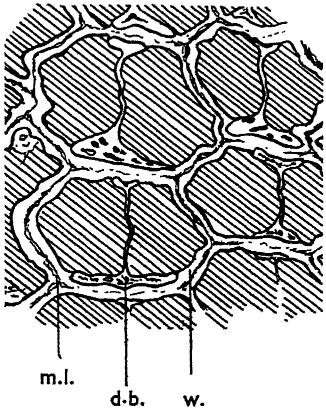

FIG. 7C.

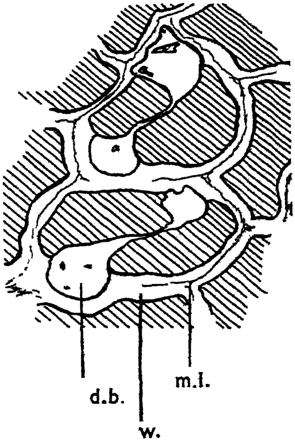

FIG. 7D.

line, but a narrower or broader band across the cell, of dumb-bell or hour-glass shape. Though no definite bounding membrane is perceptible, this band is always sharply divided from the rest of the content of the cell.

Within the band the coal substance is characterised by the presence of minute particles and gas-vesicles, and by lack of perfect uniformity. The substance which lies between the band or septum and the cell-wall, on the contrary, is remarkably homogeneous and free from all inclusions or impurities.

There are thus two contrasted substances filling the cell; the one occupying a small constricted sac which adheres firmly to the tangential walls; the other outside this sac. It is clear that nothing comparable with this is to be found in the normal living cell. On the other hand, the central sac adherent to the tangential walls is strongly suggestive of the shrunken protoplasmic sac of a plasmolysed cell. The presence of gas vesicles and lack of perfect homogeneity, moreover, seems to characterise the remains of original cell-contents. The features shown by this tissue are indeed very simply and naturally explained if the median sac be interpreted as the plasmolysed remains of the original cell contents and the homogeneous substance outside the sac as absorbed organic material. In fact it would seem that on these lines alone is any interpretation possible.

From the observations here recorded it would seem to be certain that vitrain results from the preservation of plant tissues in a fluid medium, which retained the thicker walled tissues in a pliable condition, allowing the cell walls to be compressed and often extensively contorted without any sign of fracture; the whole tissue behaving as a plastic material. Fusain on the contrary is essentially brittle; the cell walls yield to pressure only by fracture. The cells are not infilled with organic matter, and the tissue has clearly been preserved in a dry state, either due to the absence of surrounding fluid or to the inability of the medium to penetrate the tissue. In these contrasted conditions we appear to have the key to the two main modes of plant preservation in coal.

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NOTE.

[2] It seems probable that a simple division into fusain and vitrain may not be possible in all cases. In some instances vitrain of normal transparency has been found to pass into a less transparent type with open cell cavities, which merged gradually into typical fusain. Whether or not the fusain itself could have been rendered transparent by further thinning of the section is not yet clear, but there does appear to be evidence for the existence of an intermediate "vitri-fusain" having empty cell cavities, fracturing to quite typical "bogen-struktur," and yet relatively transparent.

FIGURES.

(1a) Fusain. ×300. The cell cavities are either empty or filled with mineral matter. l=cell cavity, w=cell wall.

(1b) "Bogen struktur" produced by the compression of fusain. ×300.

(2) Details of wood structures preserved as vitrain. ×1400.
l=cavity of wood fibre (compressed),
w=fibre wall, ic=intercellular space,
ml=middle lamella of wall, p=cavity of bordered pit.

(3) Tangential Section of wood vitrain. ×500.
mr=medullary ray, p=cavity of bordered pit.

(4) Radial Section of wood vitrain. ×200.
mr=medullary ray cells,
p=bordered pits.

(5a) Thick-walled cells of bark tissue that have yielded to crushing. ×400.
ml=middle lamella, l=cell cavity, w=cell wall.

(5b) Thinner-walled cells of bark tissue unaffected by stress which has caused the crumpling of the tissue shown in Fig 5a. × 400.
ml = middle lamella, l = cell cavity, w = cell wall.

(6) Thick-walled bark tissue crushed without fracture. × 400.
ml = middle lamella, w = cell wall, l = cell cavity almost completely closed.

(7) Stages in the plasmolysis of a thin walled tissue. × 700.
ml = middle lamella, w = cell wall, db = "dumb-bell."

Note the distortion of the cell wall by the "dumb-bell" and the solid material confined to the "dumb-bell." The thickness of the cell walls is really less than shown in the diagrams.

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"The Interpretation of the Spectra of CaF_2 and SrF_2."—A. Harvey, 1931.

"Fine Structure in the Arc Spectra of Bromine anc Iodine."—S. Tolansky, 1931.

"Part 1. The Activities of Certain Soil Organisms as affected by the Application of Manures. Part 2. On the Yield and Composition of Pasture Grass . . . . Cockle Park."—F. J. Elliott, 1932.

Thesis for M.A.

"Letter-writing as a Roman Art in the 1st Century B.C. and the 1st Century A.D."—Doris May Henderson, 1930.

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"Part 1. Observations on the Emission Spectra of Bromine." Part 2. The Heisenberg-Hund Theory of Line Spectra. Part 3. The Absorption Spectrum of Selenium Dioxide."—S. F. Evans, 1930.

"Studies in the Dinaphthyl Series."—J. G. Cockburn, 1931.

"A Search for Weak Absorption Bands in Fused Quartz, between ·44μ and 2·7μ also a Consideration of a Possible Spurious Effect due to Absorption in the Prism in Infra Red Work."—D. G. Drummond, 1931.

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LIST OF PAPERS READ DURING THE SESSION

1932

Nov.	22.	"Ethical Relativity." By Professor L. A. Reid.
Dec.	5.	"Some further Contributions to the Chemistry of Selenium." By Professor H. L. Riley.
Dec.	8.	"Conformal Representation." By Mr. W. H. Miles.
Dec.	15.	"Elevation of Body Temperatures by means of High Frequency Electric Fields." By Professor W. E. Curtis.

1933

Feb.	7.	"A Record of the Anthracomya librata Group from the Coal Measures of Northumberland." By Dr. W. Hopkins.
Feb.	7.	"The Morne Dyke Swarm." By S. Tomkeieff and C. E. Marshall B.Sc.
Feb.	7.	"The Preservation of Plant Tissues in Coal." By Professor H. G. A. Hickling and C. E. Marshall B.Sc.
Feb.	21.	"Some Views of a Double Standard in Ethics." By Miss D. M. Emmet.
Feb.	22.	"Supersonic Waves and their Applications." By Dr. E. G. Richardson.
March	9.	"Note on Some Specimens of Roman Copper." By G. C. Whittick and Dr. J. A. Smythe.
March	9.	"A Mesolithic Site on the Northumberland Coast." By A. Raistrick.
March	10.	"Additions to our Knowledge of the Chromosome numbers in the Lepidoptera." By Mr. H. G. Regnart.
March	10.	"Chromosomes and Phylogeny in the Geometrid Genus Oporunia." By Professor Heslop Harrison.
March	10.	"Notes on the Cytology of the Duckweeds (Lemnaceae) introducing some more general considerations on Chromosomes." By Dr. K. B. Blackburn.
March	14.	"Some Physical Aspects of Modern Quantum Theory." By Dr. J. A. Chalmers.
March	14.	"Morality in a Timeless World." By Rev. C. J. Shebbeare.
March	15.	"Our Common Birds and how to know them." By Mr. G. W. Temperley.
March	29.	"The Great Sulphur Vein of Alston Moor." By the late Lloyd M. Thompson B. Sc. read by Dr. J. A. Smythe and Edited by Kingsley C. Dunham Ph.D., B.Sc.

ADDITIONS TO LIST OF EXCHANGES PER THE UNIVERSITY OF DURHAM PHILOSOPHICAL SOCIETY FROM FEBRUARY, 1932.

Name of Institution or Society.	*Publications received in exchange.*
Aberystwyth University College.	Studies.
Belfast Natural History and Philosophical Society.	Proceedings and reports.
Belfast Naturalists' Field Club.	Proceedings.
CZEKOSLAVAKIA.	
Charles University, Prague—Plant Physiological laboratory.	Studies.
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Geologisch Bureau voor Het nederlandesche Mijingebied.	Reports.
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Imperial Council of Agricultural Research.	Publications.
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MEXICO.	
Universidad Nacional, Mexico.	Universidad de Mexico.
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RUSSIA.	
Vladivostok. Far Eastern Regional Academy of Sciences of the U.S.S.K.	Bulletins.
SOUTH AFRICA.	
Pretoria University.	Transvaal College Bulletin.
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THE CHEMISTRY OF FERMENTATION

BY

A. HARDEN, D.Sc., F.R.S.

Being the Twenty Second Bedson Lecture; delivered at Armstrong College, on 19th May, 1933.

[*Abstracted by J. G. Cockburn, M.Sc.*]

The first quantitative study of fermentation was made by Lavoisier, who was quick to interpret the anaerobic process he studied in terms of his oxygen theory as a transference of that element from one part of the molecule to another, giving a more highly oxidised product carbon dioxide, and a deoxidised compound, alcohol. The later work of Gay Lussac led to the equation :—

$$C_6H_{12}O_6 = 2CO_2 + 2C_2H_6O,$$

where it is seen that one third of the carbon of the sugar is associated with twice as much oxygen as before, and the remaining two thirds with half as much. Many attempts were made to construct schemes which would account for the products formed, as well as for the oxidation of foods to carbon dioxide and water in the organism, which was first recognised as analogous after Büchner's epoch-making discovery in 1897 that alcoholic fermentation can be carried out apart from living cells.

Two main problems have presented themselves, the manner in which the carbon chain is broken, and the products which intervene between this and the final stages. The latter problem has proved the simpler in the case of fermentations brought about by both yeasts and bacteria. The yeasts attack only simple hexoses and the 6-carbon chain breaks into two portions of three carbon atoms, possibly as methylglyoxal, $CH_3.CO.CHO$, the composition of which is one water molecule less than the half sugar molecule, or as its hydrate, $CH_3.CO.CH(OH)_2$, which is isomeric with the half molecule.[1] Methylglyoxal has, however, so far only been isolated as its bisdinitrophenylhydrazone from the fermentation products of dilute magnesium hexosediphosphate solution. It may be converted by direct addition of water by bacteria (possibly by aid of the enzyme glyoxalase and its co-enzyme which appears to be glutathione) into lactic acid. This simultaneous oxidation and reduction is typical of micro-organisms. Wieland interprets the former process as removal of hydrogen by dehydrogenases; the conversion of succinic to fumaric acid is typical:

$$HO_2C.CH_2.CH_2.CO_2H \longrightarrow HO_2C.CH:CH.CO_2H.$$

This is brought about by B. coli in the presence of methylene blue as hydrogen acceptor. In the case of aldehydes the hydrated form must be postulated:

$$\underset{\text{Acetaldehyde hydrate}}{CH_3.CH(OH)_2} \longrightarrow \underset{\text{Acetic acid}}{CH_3.CO_2H} + 2H.$$

when aldehyde may also act as hydrogen acceptor, yielding alcohol:

$$CH_3.CH(OH)_2 + 2H = CH_3.CH_2.OH + H_2O.$$

Taking these equations together we have

$$2CH_3.CHO + H_2O = CH_3.CO_2H + CH_3.CH_2.OH.$$

An enzyme catalysing this change was long ago found in liver. The transformation of methylglyoxal into lactic acid is similar.

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[1] An alternative theory of this decomposition has been recently propounded by Meyerhof. See *Nature*, Sept. 3rd, 1933.

In the alcoholic fermentation process the next stage recognised, however, is the production of pyruvic acid and glycerol from methylglyoxal in this way:—

$2CH_2{:}\ C(OH).CH(OH)_2$
Enol form of hydrate

$= \ CH_2(OH).CH(OH).CH_2(OH)$
Glycerol

$+ \ CH_2{:}C(OH).CO_2H.$
Enol form of pyruvic acid.

Pyruvic acid has been isolated as a derivative in the same way as methylglyoxal, and is almost certainly an intermediate. Then follows its decomposition into acetaldehyde and carbon dioxide brought about by an enzyme present in yeast and in many bacteria (other than those producing formic acid) which attacks all α-keto-acids and so plays a fundamental part in amino-acid metabolism :

$$CH_3.CO.CO_2H \longrightarrow CH_3.CHO + CO_2$$

This carbon dioxide is one of the final products, and acetaldehyde has been demonstrated by Neuberg's fixation technique and in other ways. It is reduced to alcohol by another molecule of methylglyoxal which is oxidised to pyruvic acid.

$$H_2O + CH_3.CO.CHO + CH_3.CHO \longrightarrow$$
$$CH_3.CO.CO_2H + CH_3.CH_2.OH.$$

A cycle is thus set up in which the fresh methylgyoxal from the sugar is converted to alcohol without much accumulation of glycerol. This last reaction (the reduction of acetaldehyde) is suppressed by the addition of bisulphite, when the acetaldehyde bisulphite compound is produced and the conversion of methylglyoxal into pyruvic acid is accompanied by the production of an equivalent amount of glycerol as explained above. In the presence of alkali the acetaldehyde is also not reduced, but gives equivalent amounts of alcohol and acetic acid, and glycerol is again formed from part of the methylglyoxal. Many bacteria do this. Interest also attaches to the bacterial production of succinic and formic acids and hydrogen, the last by a special enzyme, hydrogenlyase, recently described by Stickland and Stephenson.

The problem of the rupture of the sugar carbon chain may now be taken up. When Büchner's yeast juice, dried yeast, yeast dehydrated by acetone (zymin) or yeast in the presence of toluene is added to a sugar solution, slow fermentation ensues, which continues for a long time, dies down, and cannot be restarted by the addition of sugar. During all this period, after the first hour or so, very little inorganic phosphate is present, so that most of the phosphate must be organically combined, until the rate of fermentation begins to fall off, when it slowly reappears as inorganic phosphate. If during the steady period inorganic phosphate is added there is an immediate increase in the rate of production of alcohol and carbon dioxide while the phosphate becomes organically combined. Usually a maximum rate of fermentation is attained, and this then falls to somewhere near the old level and then continues as before. The phosphate is now found to be almost all in the organic form. The carbon dioxide and alcohol produced during the period of acceleration are roughly equivalent to the phosphate converted to the organic form. When the organic phosphorus compounds present are examined it is found that they form a complicated mixture whose nature has not yet been completely elucidated; the proportions in which the various components of this mixture occur vary greatly for a reason not yet determined. The compounds known are (1) a hexosediphosphate, probably fructofuranose-l : 6-diphosphate and (2) a mixture of monophosphates from which have been isolated glucopyranose-, fructopyranose-, and mannopyranose-6-phosphates, and possibly fructopyranose-l-phosphate, and (3) trehalose-monophosphate. In general, dried yeast and zymin yield a large proportion of diphosphate, and among the monophosphates produced by dried yeast is usually a certain amount of trehalosephosphate. Yeast juice and maceration extract are more variable, and yield practically no trehalosephosphate but as much as 80% or as little as 20% of the added phosphates as monophosphate. This is the same whether glucose, fructose or mannose is fermented. At a temperature of 38-39° mannose with dried yeast (but not with zymin) behaves abnormally, since the monophosphate fraction is largely mannosemonophosphate and the ratio CO_2: phosphate is much below unity. This is interesting because mannose also behaves abnormally in living yeast fermentations, its rate of fermentation being more affected by temperature than those of glucose or fructose.

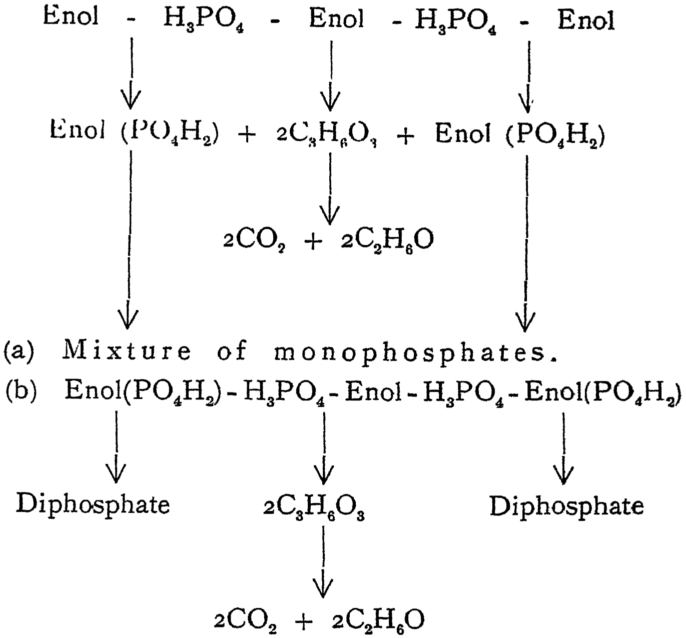
Meyerhof prepared an extract of muscle which readily converts glycogen into lactic acid and, in the presence of an activator derived from yeast, behaves to mixtures of sugar and phosphate precisely as do yeast preparations, with the exception that instead of carbon dioxide and alcohol, lactic acid is produced. The exact composition of the muscle phosphoric esters in this extract has not so far been so thoroughly examined as have those of yeast.

The next question arising is the relation of these phosphates to the accelerated rate of fermentation which accompanies their production. They are not intermediate compounds, for they accumulate during the reaction, and the latter ceases when they are present in highest concentration. Meyerhof and Euler consider that all the phosphorus passes through the state of monophosphate, and that this decomposes:

$$2C_6H_{11}O_5.H_2PO_4 \longrightarrow 2CO_2 + 2C_2H_6O + C_6H_{10}O_4(H_2PO_4)_2.$$

According to Meyerhof this monophosphate is in an activated form and part passes into a comparatively inactive form which does not undergo this reaction and is found as an end product. Euler does not assume the existence of this reactive monophosphate, and neither of them takes into account the fact that the phosphate is a complex mixture.

Although this explanation is at first sight attractive, it being a plausible supposition that the introduction of the phosphate group renders the sugar molecule unstable and capable of easy disruption, it appears inconsistent with the fact that in many, if not in all, cases the carbon dioxide is not equivalent to the hexosediphosphate but to the total phosphate esterified, of which less than 20% may be present as diphosphate. Too much stress must not be placed on these considerations, as even slight variations in conditions may greatly effect this ratio, e.g. in the case of mannose. A second explanation which the author has tentatively suggested is that this is a case of a coupled reaction; the occurrence of the esterification rendering possible a second reaction, the disruption of the carbon chain. It is to be noted that the Meyerhof-Euler decomposition of a monophosphate is a reaction of this type, one molecule being further esterified, and one broken down. Similar processes are not uncommon in biological systems, e.g., the partial reconstitution of muscle glycogen from lactic acid accompanied by the oxidation of the remainder to carbon dioxide and water. Robison has advanced as an explanation of the "coupled reaction" suggested above that the first stage is the reaction of three molecules of sugar and two of phosphate to form a complex, the sugar being in the enolic form common to the three fermentable sugars, glucose, fructose, and mannose. This then breaks down, yielding two molecules of monophosphoric ester of enolic sugar, while the third sugar molecule is disrupted into the primary products of fermentation (methylglyoxal ?). The phosphorylated enolic sugar molecules may then do either of two things, (1) Two may become associated with a fresh molecule of sugar and two of phosphate giving a similar complex which can break down to two hexosediphosphate molecules and the primary fermentation product from the third sugar molecule, or (2), the enolic phosphoric esters may pass into a mixture of monophosphates of the three sugars such as is actually found. A schematic representation of the changes is given below:

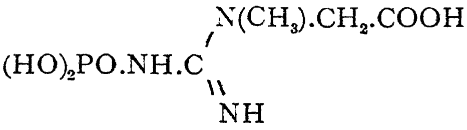

Enol - H_3PO_4 - Enol - H_3PO_4 - Enol
Enol (PO_4H_2) + $2C_3H_6O_3$ + Enol (PO_4H_2)
$2CO_2 + 2C_2H_6O$
(a) Mixture of monophosphates.
(b) Enol(PO_4H_2) - H_3PO_4 - Enol - H_3PO_4 - Enol(PO_4H_2)
Diphosphate
$2C_3H_6O_3$
Diphosphate
$2CO_2 + 2C_2H_6O$

In this case the ratio of carbon dioxide to phosphate esterified agrees with that usually found, and we have accounted for the occurrence of the mixture of monophosphates.

There is much to be said for the idea that the active substance is the enolic form of the sugars, and it seems that the occurrence of this form under normal conditions leads to a simple explanation of the mixture of monophosphates produced. Further phosphorylation would lead to an enolic di-ester which could only pass into the fructopyranose-1 : 6-diphosphate found.

What is the relation of these changes to what actually occurs in yeast and muscle? Yeast leads normally an anaerobic life, the oxygen being kept down to a low point by the carbon dioxide evolved. In common with many bacteria it has adopted, at all events as an auxiliary engine, a method other than atmospheric oxidation for obtaining the energy for carrying on the synthesis of cell constituents from the materials supplied. This was the discovery embodied in Pasteur's famous dictum: "Fermentation is life without air." Comparison of the action of the yeast cell with that of yeast preparations shows that the rate of fermentation is usually more rapid without the accumulation of phosphoric esters. Yeast preparations either give a slow rate with no accumulation or, in the presence of suitable concentrations of phosphate, a rate of the order of the living cell with esterification of the phosphate. If the yeast cell were provided with a mechanism by which the esters were decomposed as rapidly as they are formed it would explain what is observed to happen, the mechanism being much the same except that the phosphates produced are broken down rapidly (instead of only slowly as with the preparations) and the supply of inorganic phosphate thus kept up. It may be supposed e.g. that all the phosphates pass by further phosphorylation into diphosphate and that this is decomposed, but it seems highly improbable that this takes place by simple hydrolysis, but rather by a real fermentation of the molecule.

The case of muscle is even more complex, and Meyerhof, Lohmann and others have discovered a remarkable series of changes which promises to throw much light on the mechanism used both by muscle and yeast. In order to be able to provide mechanical work without being absolutely dependant on the oxygen supply, muscle has adopted what is essentially an anaerobic method for the rapid production of a certain amount of energy. Oxygen is necessary tor a continued effort. Two substances which play an important part in these changes are the "co-enzyme" of lactic acid formation which is closely related to that of alcoholic fermentation, if not identical with it, and creatinephosphoric acid. The action stops if the former is removed by washing, and it appears to be certain that it is adenylpyrophosphoric acid with magnesium ions. This is a nucleotide containing adenine, ribose, and a phosphoric group and forms a compound with pyrophosphoric acid $H_4P_2O_7$. This compound hydrolyses to, and is resynthesised from, adenylic acid and phosphoric acid. The very unstable and easily hydrolysed creatinephosphoric acid was discovered by Eggleton in 1927 and its composition almost simultaneously proved by Fiske and Subbarow to be



$$(HO)_2PO.NH.C\begin{matrix} \diagup N(CH_3).CH_2.COOH \\ \\ \diagdown\!\diagdown NH \end{matrix}$$

In each case decomposition liberates, and resynthesis absorbs, heat. Creatinephosphoric acid liberates 12,000 cal. per gram molecule on decomposition, adenylpyrophosphoric acid, 25,000, and by a further change into inosinic acid, 8000 cal.

The sequence of chemical events in muscle contraction and restitution seems to be:

(1) Creatinephosphoric acid is hydrolysed giving 12,000 cal. per molecule available for work.

(2) Adenylpyrophosphate is hydrolysed, giving 25,000 (or 33,000) cal. effecting resynthesis of the creatinephosphoric acid.

(3) Glycogen breaks down to lactic acid yielding about 17,000 cal. per molecule of lactic acid in addition to 101,000 due to its neutralisation by protein etc., effecting resynthesis of the adenylpyrophosphate.

(4) Finally lactic acid is oxidised by oxygen from the blood stream, but a further complication arises as only a part of the lactic acid is oxidised, three quarters to four fifths being resynthesised to glycogen. The total effect is that a certain amount of glycogen is used up.

The whole affords a remarkable example of the complicated interaction of chemical and physical changes which occurs in living organisms.

NEW DIATOMIC BAND SPECTRA.

BY

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Although the number of band spectra known is already very great, it is probable that many more remain to be discovered, for the variety of excitation conditions is so large that there has not yet been time to make a really exhaustive study even of diatomic molecules. In particular, attention has hitherto been chiefly concentrated on compounds having appreciable vapour pressures at ordinary temperatures, since the spectra of these are readily obtained both in absorption and emission. Therefore, it seemed desirable to examine a number of compounds for which no band spectra have hitherto been reported, although they might be expected to develop at sufficiently high temperatures.

1. Absorption Spectra.

The first compounds whose spectra were sought for were the sulphides of lead, tin, copper, silver, iron and nickel. Only one sulphide spectrum, that of germanium, has been reported,[1] and since germanium belongs to the same group in the Periodic Table as tin and lead, it was hoped that the sulphides of these two metals would give band spectra of the same type. All these substances vaporised at temperatures ranging from 800°—1300°C and this prevented the use of evacuated quartz tubes, partly because of the great difficulty in keeping the windows clean, and partly because of their destructive action on quartz.

Preliminary experiments were carried out with hollow steel tubes 12″ long by ½″ diameter open at both ends, and heated in the oxyhydrogen flame. When a transparent quartz tube of narrow bore was substituted for the steel tube, the contrast of the absorption bands was found to be improved, probably because of the greater density of the absorbing vapour in the narrower tube. Further, the use of such a tube enabled the condition of the molten sulphide to be examined, and, as this tended to distil away to the ends, it was possible, by heating the cooler parts, to maintain a steady concentration of absorbing vapour, the length of which was about 3″. At high temperatures the presence of the vapour could be detected by the resulting colouration of the scattered light emitted by the walls of the tube.

Later, vitreosil tubes were found to be as serviceable as transparent quartz tubes and being much cheaper they were substituted for the latter. These tubes, 15 cms long by 1 cm diameter, were heated in a furnace having Silit rod heating elements, with which it was possible to obtain temperatures up to 1400°C.

The sources used were:

1. For the visible region down to λ3700:—
   A 900 watt, 30 volt tungsten filament lamp.
2. For the region λ3700-λ3200:—
   An Osram 100 watt ultra violet lamp.
3. For wave lengths lower than λ3200:—

A hydrogen lamp, consisting of a quartz tube containing low pressure hydrogen, connected by external electrodes to a ½ kilowatt high-frequency oscillator giving radiation of wave length 30 metres. The pressure in the lamp dropped after some days running and OH bands became troublesome, but these were suppressed by the addition of hydrogen through a palladium tube attached to the quartz tube.

The spectra were surveyed with a Hilger constant deviation spectrograph in the visible and a Hilger small quartz spectrograph in the ultra-violet. For more accurate work, these were replaced by the Hilger E52 glass Littrow and the Hilger E1 quartz spectrographs respectively.

Details of New Spectra.

Lead Sulphide (1). This band spectrum stretches from λ3200 to λ8500 and consists of overlapping progressions of bands degraded to the red (see plate A3). It was compared with the S_2 high temperature absorption spectrum and shewn to be different. At wave lengths lower than λ3200, SO_2 bands appear shewing evidence of dissociation and at the highest temperature used, another set of bands appears at λ3500. This has been shewn to be due to PbO.

Five systems have been recognised in the PbS spectrum, all having a common ground state.

System A. $\nu = 18{,}851\cdot3+261\cdot09\,(v'+\tfrac{1}{2})-0\cdot365\,(v'+\tfrac{1}{2})^2 - 428\cdot14(v''+\tfrac{1}{2})+1\cdot201(v''+\tfrac{1}{2})^2$

,, B. $\nu = 21{,}847\cdot7+282\cdot17\,(v'+\tfrac{1}{2})-0\cdot856\,(v'+\tfrac{1}{2})^2 - 428\cdot14(v''+\tfrac{1}{2})+1\cdot201(v''+\tfrac{1}{2})^2$

,, C. $\nu = 23{,}212\cdot9+303\cdot93\,(v'+\tfrac{1}{2})-1\cdot436\,(v'+\tfrac{1}{2})^2 - 428\cdot14(v''+\tfrac{1}{2})+1\cdot201(v''+\tfrac{1}{2})^2$

,, D. $\nu = 25{,}024\cdot4+283\cdot95\,(v'+\tfrac{1}{2})-1\cdot171\,(v'+\tfrac{1}{2})^2 - 428\cdot14(v''+\tfrac{1}{2})+1\cdot201(v''+\tfrac{1}{2})^2$

,, E. $\nu = 29{,}650\cdot5+299\cdot34\,(v'+\tfrac{1}{2})-1\cdot574\,(v'+\tfrac{1}{2})^2 - 428\cdot14(v''+\tfrac{1}{2})+1\cdot201(v''+\tfrac{1}{2})^2$

The rotational structure has a simple appearance, and in all probability the transitions are between singlet levels.

Tin Sulphide (2). This gives a similar spectrum but is not so extensive, stretching from λ2600 to λ5000 (see plate A2). SnS dissociates more readily than PbS, and oxidation rapidly follows. For this reason it was found necessary to introduce nitrogen into the absorbing tube to prevent oxidation.

The vibrational analysis of these bands is in progress

It is interesting to note how the position of these spectra changes as we move down the Periodic Table from Ge to Pb.

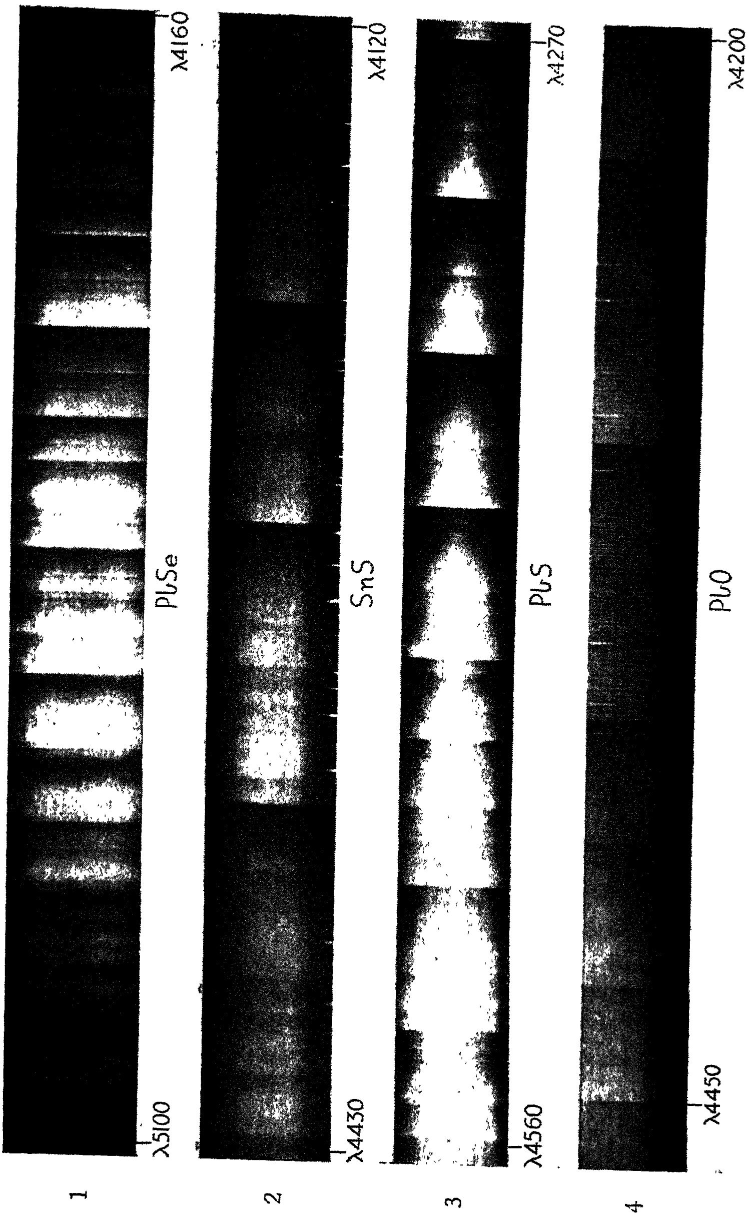
1
λ5100
PbSe
λ4160
2
λ4430
SnS
λ4120
3
λ4560
PbS
λ4270
4
λ4450
PbO
λ4200

PLATE A.

	Extent of Spectrum.
GeS.	λλ2400--3300.
SnS.	λλ2600—5000.
PbS.	λλ3200—8500.

There is little doubt that with the higher temperatures at our disposal the GeS system could be extended towards much longer wave lengths.

The Selenides and Tellurides of Lead and Tin.

These compounds which were prepared by the direct fusion of the pure elements, give extensive band systems of the same general appearance as the sulphides. In only one, however, (lead selenide (3)), has it been definitely established that the spectrum is due to PbSe and not to other lead or selenium compounds. It stretches from λ4500 to λ9000 (see plate A1). The other spectra are under investigation and there appears little doubt that they are due to tin selenide (4) and the tellurides of lead and tin (5, 6).

Other sulphides examined were those of Cu, Ag, Ni, and Fe. These give spectra which have not yet been critically investigated. Silver sulphide gives a set of bands from λ2500 downwards but whether they are due to the AgS molecule is not yet certain.

Metallic Oxides. The spectrum of litharge, PbO (7), has been photographed and the vibrational analysis is in progress. The bands stretch from λ2800-λ6000 (see plate A4). It is hoped to obtain the absorption spectra of tin oxide and copper oxide in the same way.

II. Arc Flame Spectra.

One of the writers has for some time been working on the band spectra of the oxides of iron (8), nickel (9), cobalt and copper which are excited in the flame of the arc struck between poles of the metal concerned, and this section deals with our attempt to extend this work. When only a small quantity of the metal was available, it was used in a carbon arc. In other cases, salts usually the oxide, were used in the arc.

In this way the spectra of tungsten (10), tellurium (11) and platinum oxides (12) were observed. They were all in the visible region, but as the ultra-violet region was not investigated, they may extend into it.

The flame of the silver arc shewed only atomic lines, both in the visible and in the ultra-violet, where Hulthén and Zumstein[2] found double headed bands which they tentatively attributed to AgO. As their work was confined to absorption however, our observation does not necessarily negative their suggestion. Since the emission spectrum of copper oxide is in the red, it is probable that that of silver oxide is to be found in the infra red.

Molybdenum oxide (13) gave a strong continuum throughout the visible with an intensity maximum in the blue.

A high current arc (20—25 amps) containing cerium oxide (14) shewed a small blue-green band system which was contaminated with strong AlO and LaO bands.

Thorium oxide (15) under the same conditions gave a blue system different from that of CeO, but masked by the same impurities.

No bands were obtained from an arc fed with metallic thallium.

Nitride Spectra. An attempt was made to obtain the spectra of magnesium and aluminium nitrides by running an arc in nitrogen, but no bands were observed.

III. High-Frequency Emission Spectra.

Another method of exciting spectra is that of the high-frequency discharge using external electrodes. As such a discharge can be produced at very low pressures, it is apparent that this method is particularly suitable for substances possessing a very small vapour pressure. Further, the absence of internal electrodes eliminates the possibility of contamination from such a source.

The high-frequency oscillator used was that described on p. 127. External heating was always necessary to maintain the discharge.

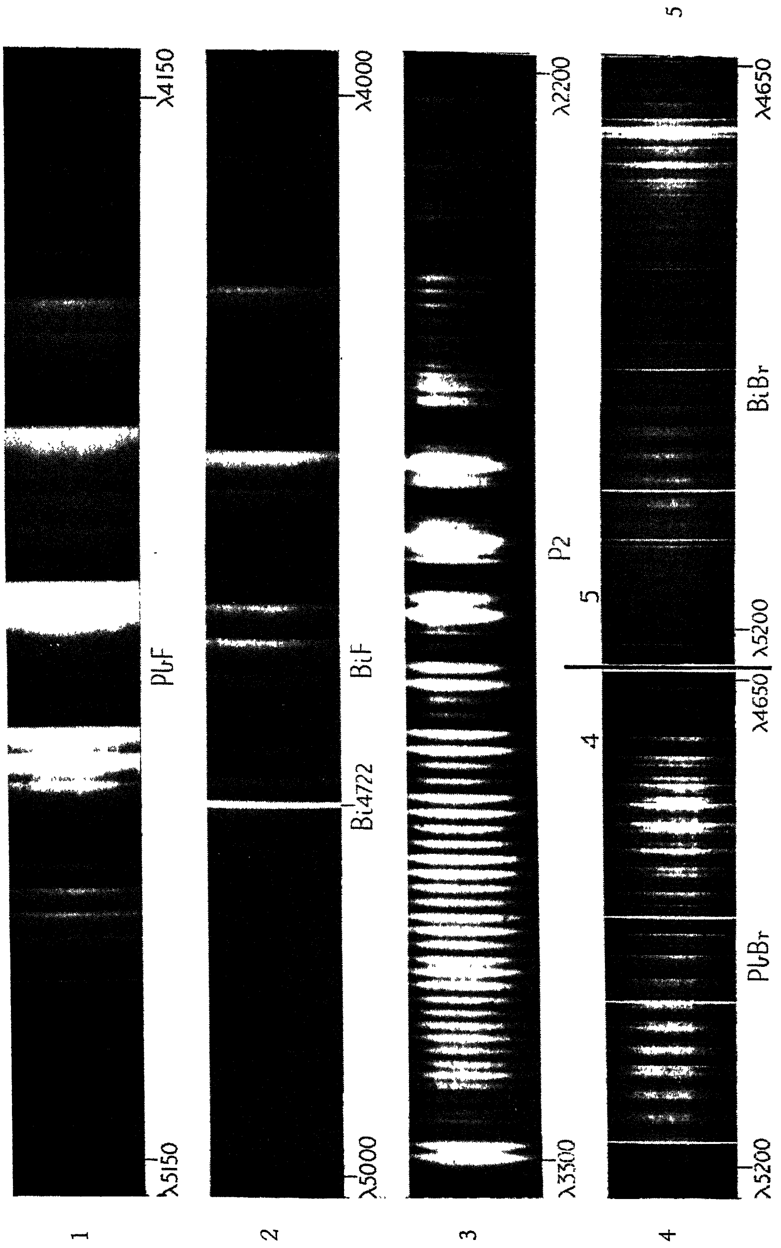
1
λ5150
PbF
λ4150
2
λ5000
Bi 4722
BiF
λ4000
3
λ3300
P2
λ2200
4
λ5200
PbBr
λ4650
4
5
λ5200
BiBr
λ4650
5

PLATE B.

The lead halides (16-19) were the first substances to be investigated, and in every case an emission spectrum was observed and photographed in the visible region. Lead fluoride (16) in particular gave an intense set of sequence type bands completely free from any carbon spectrum contamination. (See plate B1.)

Bismuth fluoride (20) gave a visible band system which possessed a striking similarity to the PbF system. (See plate B2.)

Bismuth bromide (21) gave a spectrum which also resembled in general appearance that of the corresponding lead salt. (See plates B4 and 5.)

Encouraged by the ease with which the PbF and BiF spectra were produced, we next examined the fluorides of aluminium, cerium, chromium, manganese, iron and nickel, but with disappointing results. In all cases, the most prominent feature of the spectrum was the appearance of the SiF bands, and only with iron fluoride (22) was a new spectrum obtained. This substance unfortunately discoloured the tube with a dull red deposit which was not removed by heating.

The fluorides of lead and bismuth were made in the pure anhydrous state, whereas the other fluorides were commercial samples containing water of crystallisation. It is to this fact that we attribute our failure to produce these spectra.

Tin bromide (23) gave a very strong continuum beginning at λ6500 and ending abruptly at λ4400. From λ4400-λ3750 was a series of diffuse bands followed by a continuum with a maximum at λ3600, and another set of diffuse bands similar to some which appear in the SnCl system and which, indeed, may be due to chloride impurity. Before analysis of this spectrum can proceed, it will be necessary to compare it with the bromine emission spectrum.

Tin iodide (24) gave a similar spectrum to the bromide with a visible continuum, and diffuse bands from λ4900 downwards with sharp heads at λ4150 and λ4350. The presence of iodine was shown by the λ3460 continuum.

The fluoride was not examined owing to the difficulty of preparation.

Antimony chloride (25) gave bands between λ3200 and λ4000 although chlorine continua were also present.

Antimony bromide (26) shewed an extensive band system beginning at λ4000 and extending to λ2800.

Antimony iodide (27) gave a spectrum in which the iodine λ3460 continuum was prominent. There were also diffuse bands in the same region, and it will be necessary to take photographs with higher dispersion before any decision as to the nature of the emitting molecule can be made.

Phosphorus halides. The chloride, bromide and fluoride of phosphorus all gave a large ultra-violet spectrum stretching from λ3600 to the far ultra-violet. Red phosphorus also gave the same system, and as its appearance corresponds with the description of the P_2 emission spectrum given by Herzberg,[3] there is no doubt that P_2 is the emitting molecule.

Thallium halides (28-30). The fluoride, chloride and bromide gave similar band spectra which occurred in the following regions :—

TlF (28) λλ4500-3250.

TlCl (29) λλ4200-3200 and another set λ3100-λ2900.

TlBr (30) λλ4700-3450.

Manganese chloride (31) gave a set of diffuse bands between λ4000 and λ3500.

DESCRIPTION OF PLATES.

PlateA. Absorption Spectra.

1. Lead selenide.
2. Tin sulphide.
3. Lead sulphide.
4. Lead oxide.

Plate B. Emission Spectra.

1. Lead fluoride.
2. Bismuth fluoride.
3. Phosphorus. Same bands obtained with PCl_3 and PF_3.
4. Lead bromide.
5. Bismuth bromide.

REFERENCES.

[1] Shapiro, Gibbs and Laubengayer. Phys. Rev. 40, 354, 1932.
[2] Hulthén and Zumstein. Phys. Rev. 28, 13, 1926.
[3] Herzberg. Nature. 126, 239, 1930.

NEW SPECTRA.

	Oxide	Fluoride	Chloride	Bromide	Iodide	Sulphide	Selenide	Telluride
Lead	A7	E16	E17	E18	E19	A1	A3	A5
Tin	X		X	E23	E24	A2	A4	A6
Copper	X	X	X	X	X	?		
Bismuth ...	X	E20	X	E21				
Silver	—		X	X	X	?		
Iron	E8	E22				?		
Nickel	E9	—				?		
Thallium	—	E28	E29	E30				
Antimony ...	X		E25	E26	E27			
Cerium	E14	—						
Manganese	X	—	E31					
Phosphorus	X	—	—	—				
Aluminium	X	—	X					
Molybdenum ...	E13							
Tungsten	E10							
Platinum	E12							
Thorium	E15							
Tellurium	E11							

TABLE REFERENCE:

E	Emission spectrum.
A	Absorption ,,
X	Bands already known.
—	Negative result obtained.
?	Bands present but require verification.
Numeral	Refers to new bands in text.

THE CHROMOSOMES OF SOME BRITISH ORCHIDS

by

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The present studies are the outcome of an indiscriminate collection and preparation of material of native Orchids, made while gathering specimens for a cytological investigation of the genus *Orchis*. The results of these observations have been incorporated together in the belief that they may be of value to other workers on the family, and in the hope that they are of some service to the taxonomist in helping him to determine the generic position of one or two of the species about which there are still many differing opinions.

The widely divergent nature of the relationships of some of the species under investigation, and the small number of observations, make any discussion on the problem of "Chromosomes and Phylogeny" valueless. As such, it is felt unnecessary to report the results of investigations by other workers on the cytology of the family *Orchidaceae*, unless they have a direct bearing on the subject.

There are so many views concerning the generic position of some of the species under examination, that I have included a list of the more common synonyms, and the nomenclature used in Druce's British Plant List has been adopted.

Somatic metaphase plates were obtained in tubers and developing ovules, as well as in root tips. Anthers were fixed with Carnoy's formula, while Langlet's chrome-acetic formalin solution was employed for the fixation of roots, tubers and ovaries. The subsequent staining was carried out by Heidenhain's Iron Alum technique. Sections were cut at 10μ. Drawings were made at magnification of X 3000 ca. using camera lucida at bench level.

Gymnadenia conopsea R. Br.

Synonyms :—

Habenaria conopsea Benth.

Platanthera conopsea Schlect.

The somatic complement was examined in root tips, and was seen to contain 40 chromosomes. These were "sausage-shaped" in form, and with the exception of one pair of chromosomes which sometimes appeared to have a median or sub-median constriction, there was no clear evidence as to the position of the spindle fibre attachment (see fig. 1). The behaviour at reduction division in the anthers was perfectly normal, and a reduced number of 20 bivalents were present in 1st metaphase plates. These bodies were practically spherical in form when seen in polar view. (See fig. 2.)

In both somatic and meiotic metaphase plates the chromosomes were very frequently strung up together in chains. This phenomenon was observed to a greater or less extent in all the species under examination. It is probable that this is merely an artifact caused by the fixation, but until further studies have been made on this problem, by a comparison of different fixatives, no definite conclusions can be reached about this point. It is significant however, that Hoffman (1930), in reporting the results of his investigations on the chromosomes of several genera of the *Orchidaceae*, found the same appearance, and was able to diminish it to a certain extent by following Kihara's cold technique in fixation (1927).

The occurrence of 40 chromosomes in this species gives a fourth chromosome number. The previous studies have been carried out by Strasburger (1888) who reported finding 16 somatic chromosomes, Chodat (1924) (see Hoffman) $n=8$, and Fuchs und Ziegenspeck (1924) who found $n=10$, $2n=20$. It is evident that these numbers fall into two polyploid series—namely, $n=8$, 16, and $n=10$, 20. It is conceivable that an error has been made and that the numbers 8 and 10 are one and the same, but it is more difficult to see how 16 and 20 could have been confused. Further examination is necessary to clear up this point. The old position that a species is characterised by a single chromosome number is now no longer tenable, but it is still rather unusual to find two such polyploid series within the confines of a single species.

Platanthera bifolia Rich

Synonyms :—
Habenaria bifolia R. Br.
Gymnadenia bifolia Mey.

Forty-two somatic chromosomes are present in the form of curved rods, with no clearly defined constrictions, although a few were more pronouncedly bent medianly, or sub-medianly. They are slightly longer than those of *Gymnadenia conopsea,* and are aggregated together into clumps as in that species (see fig. 4).

Plantanthera chlorantha Reichb.

This species has been placed at various times in the genera *Orchis, Gymnadenia, Habenaria* and *Platanthera,* with *virescens, bifolia, montana* or *chlorantha* as its secondary title.

Forty-two chromosomes were seen very clearly in somatic plates in the roots. These varied in the amount of contraction from the long curved rod-like forms, similar in every respect to those of *P. bifolia,* to shorter and more rectangular bodies (see fig. 3).

The two species of *Platanthera* which I have just discussed, have previously been investigated by Afzelius (1922) and my results confirm his observations. He also reported a polyploid species for this genus, *P. obtusata* with 63 chromosomes. Brown (1909) found the number of chromosomes for *P. ciliaris* to be $n=16$. The complements of *P. bifolia* and *P. chlorantha* were very similar and I was unable to detect any difference between them.

Coeloglossum viride Hartm.

Synonyms :—

Habenaria viride Br.
Plantanthera viride Lindl.

An examination of somatic plates in tubers revealed 40 small irregularly round chromosomes (see fig. 5). In some plates the chromosomes were rod-like and although smaller, resembled those of *G. conopsea.* The meiotic process was followed in anthers and was seen to be quite regular with 20 bivalents. (Fig. 6.) The chromosomes of the second division were much smaller and possessed median or sub-median constrictions in many cases (fig. 7). Two chromosomes in the somatic plates gave some indication of a constriction, but their highly contracted state made its discernment very difficult.

Goodyera repens R. Br.

Synonyms :—

Satyrium repens L.
Epipactis repens Crantz.
Serapias repens Vill.

Somatic chromosomes were discovered in the integuments of developing ovules and were seen to be 30 in number (fig. 8). They were very small, and round or oval in form. Meiosis was regular with 15 slightly larger, and more angular bivalents (see fig. 9).

The chromosome complements of *Gymnadenia* and *Platanthera* are very similar to those of many other genera of *Orchidaceae* investigated by Hoffman (1930), who shows that this type is characteristic of large numbers of species within the family.

SUMMARY

1. Somatic and meiotic division were examined in *Gymnadenia conopsea* and 40(2*n*) and 20(*n*) chromosomes were observed. Meiosis was quite regular. This constitutes a new number for the species; three others, 8, 10 and 16*n* having been previously reported.
2. 42 somatic chromosomes were found in *Platanthera chlorantha* and *P. bifolia*, thus substantiating Afzelius' work.
3. 40(2*n*) with 20(*n*) chromosomes were found for *Coeloglossum viride* while *Goodyera repens* has 30(2*n*) and 15(*n*). Meiosis was regular in both cases.

The author is indebted to Prof. J. W. Heslop Harrison and Dr. K. B. Blackburn of the Botany Dept., Armstrong College, Durham University, for laboratory facilities and their unfailing interest in the progress of the work.

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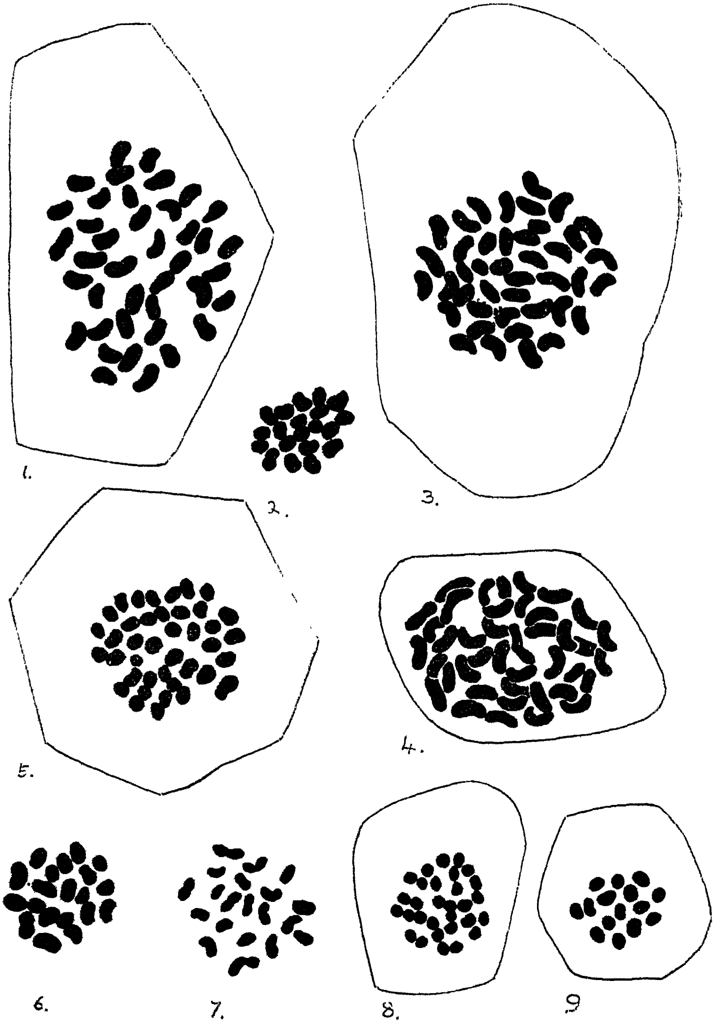


Figs. 1, 2. *Gymnadenia conopsea.*
1. Somatic chromosomes.
2. 1st metaphase of meiosis.

Fig. 3. *Platanthera chlorantha.* Somatic chromosomes.

Fig. 4. *Platanthera bifolia.* Somatic chromosomes.

Figs. 5, 6, 7. *Coeloglossum viride.*
5. Somatic chromosomes.
6. 1st metaphase of meiosis.
7. 2nd metaphase of meiosis.

Figs. 8, 9. *Goodyera repens.*
8. Somatic chromosomes.
9. 1st metaphase of meiosis.

Illustrations reduced Half.

EXAMINATION OF A ROMAN CHISEL FROM CHESTERHOLM.

BY

C. E. PEARSON, M. MET. and J. A. SMYTHE, D.Sc.

This chisel was found by Mr. E. Birley during the course of his excavations at Chesterholm in 1932. The date assigned by him is the second century A.D. A sketch of the chisel is shown in fig. 1. It is 8 ins. long with a square head 0·9 ins. across, and a square sectioned body of about 0·4 ins., tapering slightly from the head downwards. The section is reduced over a length of 0·75 in. to form the chisel edge, which is slighty splayed to 0·5 in. wide. The form of the present edge suggests that the actual cutting edge has been lost by corrosion to the extent of not more than 0·2 in. The weight, after removal of the thick coating of rust and earthy material, was 165 gms., mostly sound metal.

For the purpose of examination the chisel was planed lengthwise through the middle. The planings were used for chemical analysis, the results of which were as follows:

	Per Cent
Manganese	nil.
Silicon	0·038
Phosphorus	0·016
Sulphur	0·011
Nickel	nil.

Carbon was not determined analytically for its distribution in the metal, as shown metallographically, was so variable that an average value is of little or no significance. It will be observed that the amounts of the common impurities are very small. The figures may be compared with those obtained for a bloom of iron from Corstopitum.[1]

A macro-examination of the planed chisel disclosed comparatively little cinder in the metal, except near the

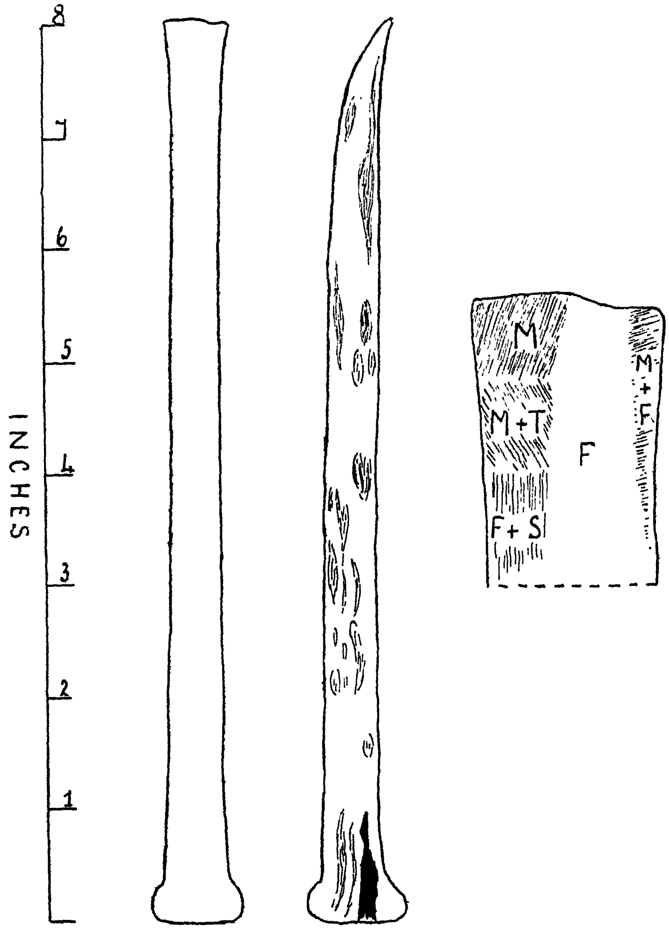


FIG. 1.—Roman Chisel, Chesterholm.

Left : Back or front view showing the splaying near the edge of the tool.

Middle : Longitudinal section at right angles to this, showing distribution of steely parts (shaded) and cinder (black). The white areas are ferrite.

Right : Tip of chisel (enlarged) showing roughly the areas occupied by the metallographic constituents.

M = martensite ; T = troostite ; S = sorbite ; F = ferrite.

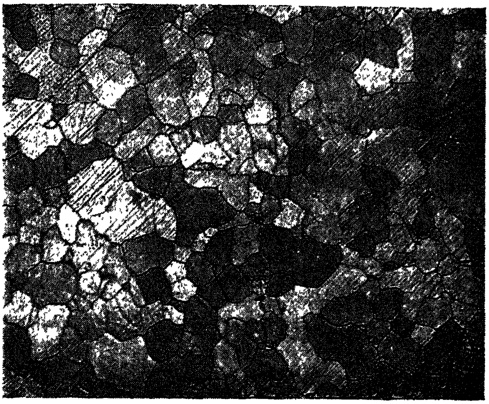


FIG. 2.—Ferrite structure typical of about one half of the chisel.

x100.

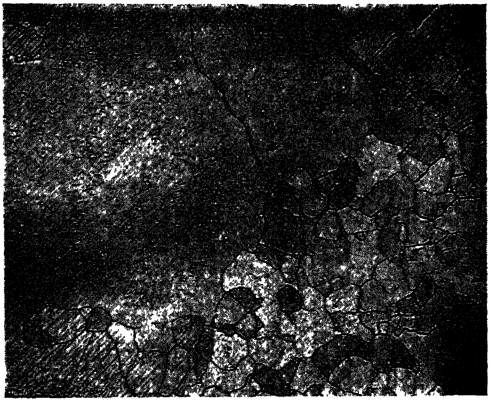


FIG. 3.—Fine and coarse grained ferrite, the latter showing cementile needles.

x100.

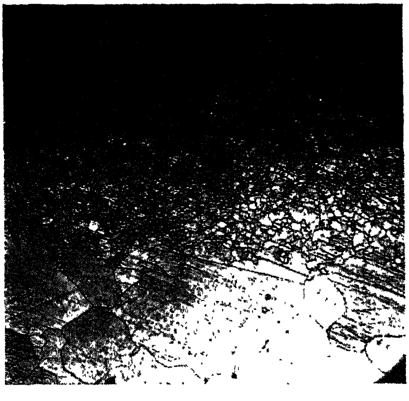


FIG. 4.—Rapid alteration in carbon content.

x100.

head where there was a large inclusion. The carbon was distributed as steely areas in the shape of curving wisps and lenticles. Both cinder and steely areas were drawn out roughly parallel to the long axis of the chisel.

The detailed metallographic examination of the chisel may be summarized under four main heads.

(1) About half the chisel consists almost entirely of ferrite (fig. 2), the crystal grains of which vary in size within wide limits. In the central parts of many of the largest grains there has occurred a separation of cementite, Fe_3C, in the form of minute needles. These are absent in a zone of uniform width next to the grain boundaries, along which there is a semi-continuous film of cementite (fig. 3). The small grains show no internal separation of cementite, though again this constituent is frequently present as an intergranular boundary film. The occurrence of carbon in the form noted above, instead of as the pearlite constituent, has been observed in very low carbon steels by several workers,[2] and is usually attributed to the formation at high temperatures of a solid solution of ferrite and carbide (to the extent of 0·03% carbon at 750°C) from which there occurs on cooling a separation of carbon as cementite; the solid solubility of carbon in ferrite at ordinary temperatures being almost nil.

(2) The steely portions of the chisel, consisting structurally of pearlite and ferrite, or pearlite and cementite, show a variation in appearance, frequently within a distance of 0·5 m.m., from that of a dead mild steel to that of a high carbon steel (fig. 4). The structure of the area of highest carbon content that was found, estimated at 1·3% carbon, is shown in the photomicrograph (fig. 5).

(3) About one half of the chisel edge consists of martensite and troostite (fig. 6). The presence of these constituents, together with the coarse nature of the martensite indicate that the edge of the tool has been heated to a temperature of, approximately, 900°C and has then been quenched in water. When the structure is traced away from the cutting edge the hardening constituents are

replaced by those formed by slower rates of cooling and pearlite is found at a distance of 0·75″ from the edge, showing conclusively that the attempt made to harden the tool had been confined to the cutting edge. The other half of the chisel edge is free from carbon and consists of ferrite. The absence of carbon in this area has nullified the hardening process locally, since the formation of the hard constituent, martensite, is dependent on the presence of carbon.

(4) On the head of the chisel the granular structure is much distorted, the grains being flattened parallel to the top surface, as shown in fig. 7. This is the only place which shows any evidence of cold deformation of the metal.

Numerous determinations of hardness have been made on the metal by means of the Vickers machine. One advantage of this machine is that the indentations are very small and thus the hardness of selected areas can be measured and compared with the micro-structure, even in a metal so heterogeneous as that under discussion. In the following table are given the average values of hardness in the metal comprising the body of the chisel, compared with the carbon contents roughly estimated from the structure at the points of indentation.

Carbon per cent.	0.0	0.1	0.2	0.3/0.4	0.5/0.6	1.3
Hardness number. V.P.N.	136	114	149	169	214	233

These figures agree on the whole with the values to be expected, though the hardness of the ferrite is distinctly higher than is usual in unstrained metal. The deformed metal on the head of the tool has a much greater hardness, being 212 where the structure consists of ferrite only and 218 where about 0·1 % carbon is present. At the hardened edge where the structure is almost entirely martensite the highest value found is 579.

The observations detailed leave one in no doubt as to the origin and use of the chisel. All who have worked on these irons of early days have commented on their heterogeneity of structure which is a necessary consequence of

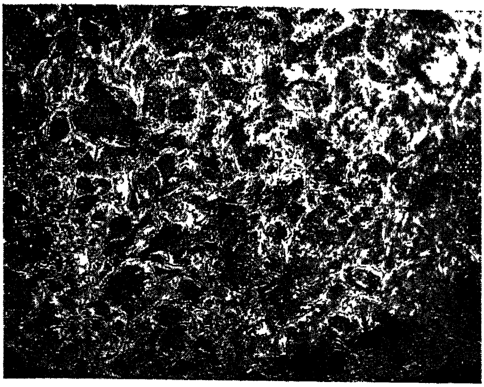
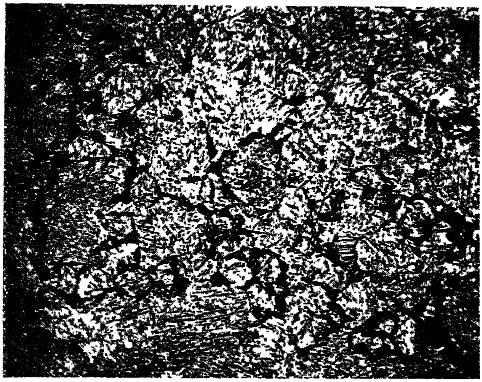


FIG. 5.—High carbon area (carbon about 1.3 p.c.) associated with cinder.

x100.

FIG. 6.—Course Martensite and Troostite near chisel edge.

x100.



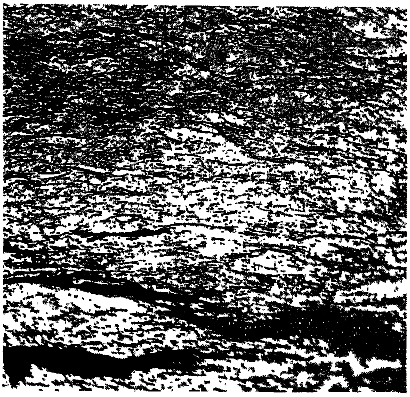


FIG. 7.—Flattened granular structure at the head of the chisel.

x100

smelting in primitive furnaces. In these, small blooms of pasty metal, mixed with cinder were obtained, which with much hammering and many re-heatings were wrought into shape. Complete separation of cinder from metal was impossible and the varying conditions in the furnace made it inevitable that some parts of the metal should be richer in carbon than others. Later forgings, though tending to equalization in composition, still left the metal streaky, bands of iron and of steel of varying composition alternating with one another.

Judging from the statements of Pliny,[3] the Romans were well acquainted with the method of hardening steel by quenching and they even practised such refinements as the use of oil, in place of water, for delicate articles. Metallographic evidence of this is afforded by the occurrence of martensite in tools of the 1st century A.D. from Römhild, Thüringen.[4] More recently it has been shown that the Egyptians from 1200 B.C. onwards were acquainted with carburizing and quenching, as methods for hardening steel tools.[5] Perhaps the main interest in the present case is that local heat treatment has been applied with the evident object of hardening the cutting edge, but has partly failed in its purpose because of the omission of the preliminary carburization and the great variation in carbon-content in different parts of the metal. The result is that about half the edge is martensitic and has a hardness from 464-579, and the other half is soft iron with a hardness of only 138. It is clear that the artificer has not understood the process fully. Notwithstanding the imperfection of the chisel in this respect it has nevertheless been used as a tool, as is proved by the signs of cold-working on the head.

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THE ACOUSTICAL FUNCTIONS OF THE LARYNX.

By

E. G. Richardson, B.A., Ph.D., D.Sc.

The human vocal apparatus consists of the chest (bellows), larynx containing the vocal cords (source of vibration) and the throat, mouth and nasal cavities (resonators). The production of tone has often been likened to that in a reed pipe of the wood-wind class but perhaps a brass instrument of the trombone type gives a closer analogy, since both the size of the resonators and the tension and length of the vibrating tissues are adjustable. The true or lower vocal cords are set in vibration by approximating their edges under the tension necessary to produce a note of the required frequency, and the breath expelled through the narrow slit between them. This process sets the edges in vibration either as a whole (normal register) or in part (falsetto register). These vibrations may be seen with a combination of the laryngoscope and stroboscope. The mathematical theory of this vibrating system has been given by Wegel.[1] Experiments on excised larynxes have shown that, as would be expected, the quality of the unaided vocal cords is raucous and unmusical. It is mainly by the modulating influence of the resonating cavities upon the laryngal tone that man is able to transcend the lower animals in speech and song, though the parrot and certain members of the ape family possess this faculty to a limited extent.

There lie above the true vocal cords two bands of tissue often called the false vocal cords, the action of which has often been misunderstood or ignored. Authoritative text-books on the larynx are mostly silent as to the purpose of these ventricular bands, although it is known that they can be moved and brought together in spite of the fact that the activating muscles are weak.[2] The higher apes and the human being can with some difficulty set them in vibration at the same time as the lower ones so producing a double note or chord. Normal persons employ the ventricular bands only to favour certain tones in the vocal cord vibrations by bringing the two sets into greater or less proximity. In singing a high note, for instance, the whole larynx is raised in the throat, thus compressing the organ in a vertical direction and accomplishing the approximation of the two pairs of cords. So much can be seen through the laryngoscope.

It is here suggested that the rôle of the false vocal cords is similar to that of the upper lip of the (flute) organ-pipe or of the sharp rim in the mouthpiece of the trombone, where it joins the main tube of the instrument, i.e., that an 'edge tone' is produced between the two pairs of vocal cords. Just as in this orchestral instrument, from the congeries of vibrations of all frequencies imposed on the breath emerging from the lips that particular edge tone is selected and amplified which is appropriate to the physical conditions prevailing, so the producer of the human voice is able to purify the cord-tone by a suitable adjustment of the relative position of the two sets of vocal cords. The edge tone law is a simple one though not easy to derive theoretically. If a jet of fluid emerges from a slit with a given velocity to fall upon an edge at a fixed distance from the slit, the frequency of the tone produced is given by

$$\frac{1}{2}\,\frac{\text{Velocity of Blast}^3}{\text{Distance from Slit to Edge}}$$

In the human larynx (shown in vertical section on Fig. 1) the slit SS is formed by the true vocal cords while there are a pair of 'edges' EE formed by the false cords, one each side of the issuing jet, available for assisting tone-production. We see from the formula that high-pitched notes will be favoured by breathing hard through SS and at the same time making the distance SE as small as possible. (The trombone player does exactly the same thing; he pushes his lips forward towards the edge of the mouthpiece and blows harder to produce a high note.)

This part of the vocal apparatus is most closely copied by those decoys or bird-calls consisting of a flattened metal capsule having two circular holes facing each other through which one blows.

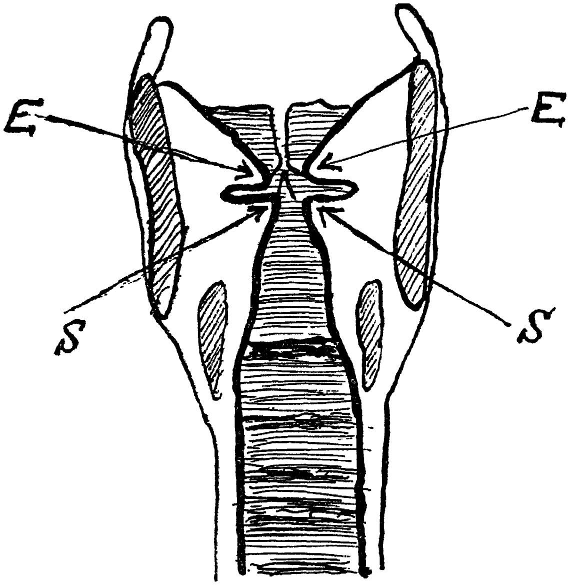

Fig. 1.

To illustrate the difference between the edge-assisted and the unassisted jet in voice production an apparatus was set up in which the state of affairs could be imitated by the motion of a coloured jet of water. A nozzle having a linear orifice 1 in. long was submerged in clear water in a glass bowl about 1 ft. 6 in. diameter and water fed to it together with two fine threads of blue ink so that a flat jet was delivered in a horizontal direction with its edges coloured by the two filaments of ink. Facing the nozzle and about $\frac{3}{4}$ in. away was placed a slit whose width was adjustable. The slit was formed between two metal plates, which could in fact be drawn aside in grooves quite

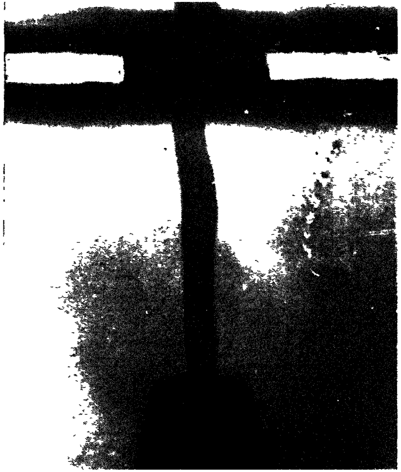

Fig. 2

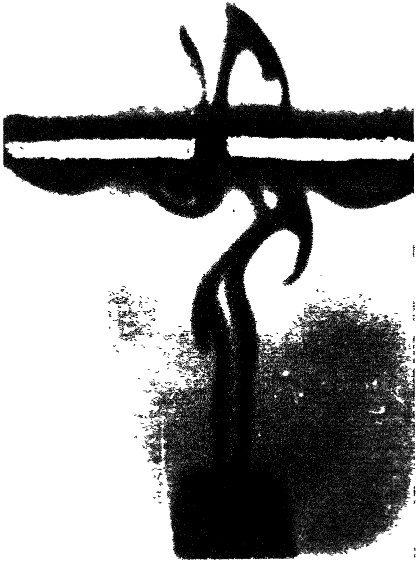

Fig. 3.

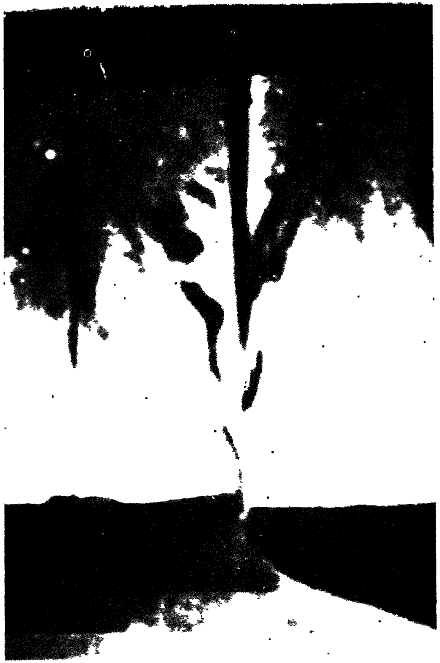

Fig. 4.

clear of the jet when required. Under these latter conditions the jet was but slightly disturbed by oscillations communicated to it in the nozzle, and with no marked frequency. Fig. 2 shows a photograph of the jet taken from above. The white lines on the black background show the boundaries of the slit. When however the slit was narrowed to about $\frac{1}{10}$ in. oscillations of one particular frequency (viz. that given by the edge-tone formula) were amplified, and produced marked periodic vortices in the jet passing through the slit (cf. Fig. 3). In the same way in the human vocal apparatus oscillations of a particular frequency in the 'puffs' issuing from the lower vocal cords may be stimulated by appropriate adjustments of the relative position of the upper cords, and the velocity of the breath. The extent to which this is actually done depends on the individual and as we have said is most obvious in the production of the higher notes. Fig. 4 shows for comparison the oscillations of a jet striking a single edge, as it does at the mouth of an organ pipe.

We turn to the important modifications produced on this still rather unmelodious 'buzzer' note by the resonance column which it now has to pass through. The natural vibrations of the latter in the absence of a buzzer note may be heard in whispered speech or in whistling, when the vocal bands are drawn aside and a stream of air passes through practically uninterrupted at the larynx. Phoneticians usually distinguish three principal resonances, the back cavity (throat), the front cavity (of the mouth) and the nasal cavity. The acoustic impedance of the latter is then a 'shunt' upon the front part of the mouth. Further the nasal cavity may be completely cut out, in the production of certain sounds, by the large impedance of the constriction where it joins the throat. In the absence of damping each cavity may be regarded as an acoustic capacitance and each constriction as an inertance. Thus, writing C_1, C_2, C_3—the capacitance of the throat, mouth and nose respectively, L_0 the inertance of the constrictions between back and front mouth-cavities (formed by the arch of the tongue), L_1 between throat and nose (formed by the uvula), L_2 at the lips, and L_3 at the nostrils, the total impedance to oscillations of frequency $\omega/2\pi$ will be

$$\frac{\omega\,(L_0+L_1+L_2+L_3) - (1/\omega C_2+1/\omega C_3)}{[\omega(L_3+L_1) - 1/\omega C_3]\,[\omega(L_2+L_0) - 1/\omega C_2]} - \frac{1}{\omega C_1}$$

A component cord-tone of a frequency which makes the total impedance as small as possible will be magnified in the wave-form of the resulting emitted sound over and above one for which the impedance is large.

In particular if ω satisfies the equation :—

$$\omega^4[(L_0+L_2)\,(L_1+L_3) - C_1(L_0+L_1+L_2+L_3)] - \omega^2[(L_1+L_3)/C_2 + (L_0+L_2)/C_3] + (C_1+C_2+C_3)/C_1C_2C_3 = 0.$$

the impedance is zero and the amplitude infinite. There are many variables in this equation, which means that the same sound can be produced in a number of ways. There will be linguistic and dialectal differences in the method of producing the same vowel. For instance a person who either because of disease or from habit (as in the case of Tyneside speakers) normally kept his lips somewhat closed, would have to compensate this low value of L_2 by a change in some other factor. Negus[4] records the case of a man who had his tongue almost completely removed and yet could sound vowels quite well. Of course the division into cavities and inertances must not be regarded as too rigorous. In some vowels the whole resonance system approximates to a wide open funnel stretching from larynx to lips. Actually the damping is very large, much more so than in a wind instrument, owing to the resilient nature of the walls of the cavities. This has the practical effect of broadening all the resonances. It makes, in fact, the testing of the natural resonances of the system held in a given position by such methods as bringing tuning forks in front of the mouth rather difficult. Again, although tables of resonances for various vowels are given, there are small discrepancies between the resonances detected by different investigators, and those not entirely due to phonetic uncertainties, e.g. in the pronunciation of the vowels or the pitch of the cord note. Damping tends in fact to confound together the theories of Helmholtz and Hermann on the subject of the wave forms of vowels.

While it is true that we find, with the latter, that as one sings a vowel up the scale, each cord-note has the 'formant' of the fixed resonance cavities impressed upon it, these resonances are so broad that the probability will be that a number of the harmonics of the cord-note will elicit some resonance in the mouth cavities, giving apparent agreement with the Helmholtz relative pitch theory of vowel overtones. This has the result that within limits the wave-form of a vowel is preserved as the cord-note is changed. This would not be so in a brass instrument where rigid walls and consequent sharp resonances impress a very pronounced 'formant' on each note, altering the wave form as the player moves up the scale. The wave-forms obtained by Curry[5] with the cathode ray oscillograph indicate that the actual maintenance of the air vibrations by the vocal cords is of the same nature as the 'relaxation' oscillations whose theory has been given by van der Pol.[6] It must be remembered that in ordinary speech the resonances of the cavities lie mostly above the fundamental of the cord-note used to excite them. In this form of sub-synchronous maintenance the cord fundamental may be regarded as a periodic impulse like the occasional push which will maintain a swing. The forced system relaxes after each impulse in a series of damped vibrations until its displacement is renewed by the next impulse. On this point we are in agreement with Scripture.[7] Such relaxation oscillations are noticeable in a number of vowel wave-forms.[8]

This note was written to illustrate certain aspects of the work done in the Phonetics Laboratory at Armstrong College, and I am indebted to my colleagues Messrs. R. Curry and H. Orton for a number of helpful suggestions in its preparation. We would like to take this opportunity of expressing our thanks to the College Council, and to

Professors W. E. Curtis and W. L. Renwick for their active support of this work by the provision of the laboratory and its equipment. I should also like to thank Dr. L. A. Sayce for the loan of the camera used.

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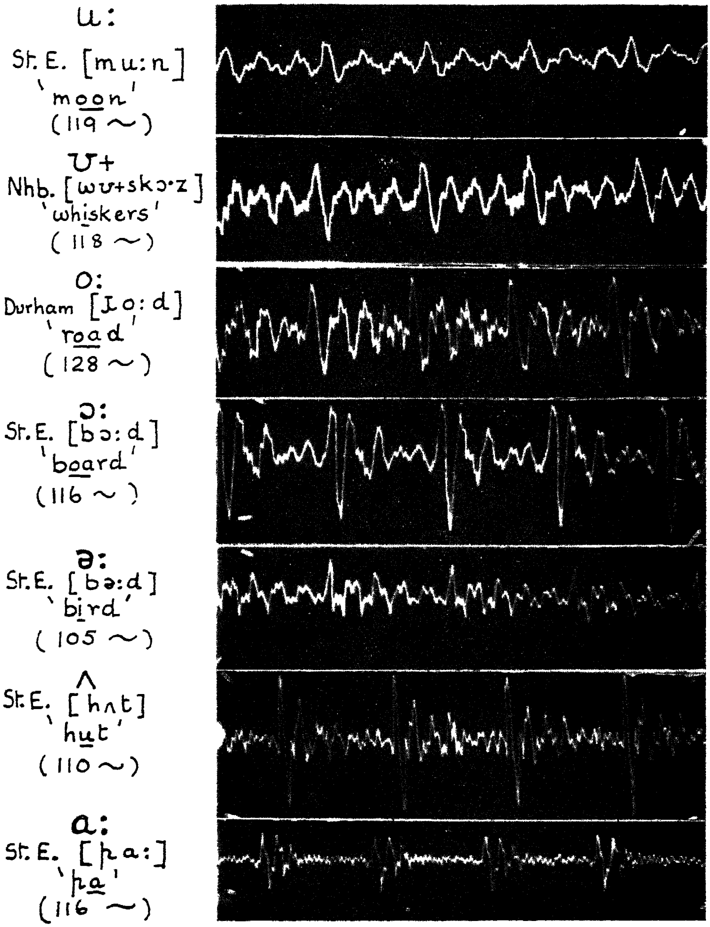
STUDIES IN MODERN ENGLISH SPEECH, ON THE BASIS OF RECORDS WITH THE CATHODE RAY OSCILLOGRAPH.

By

ROBERT CURRY, M.A., Ph.D.

This method of recording and analysing speech-sounds is an application of the principle by which a medium-voltage Cathode Ray Oscillograph may be used to record with a high degree of accuracy alternating currents and voltages at high frequencies and having very complicated waveforms. The general principles of the method and the means of recording on cinematograph film travelling at the speed of 6 ft. per second have been described previously (1). The calibrated microphone and amplifier transmit the speech-sounds as an alternating potential, which is applied across one pair of deflection plates of the Oscillograph. The microphone and amplifier have been calibrated by means of a standard sound-source, energised from a heterodyne audio-frequency oscillator and independently calibrated in free air with a Rayleigh disk. The calibration curve of the microphone and amplifier does not vary by more than 3 decibels from an uniform response over the frequency range of 50—9000 cycles. The normal range covered by the human voice in speech extends from about 64 to 6000 cycles. The Oscillograph used is a Cossor type C Photographic Blue-response pattern and is operated at an anode potential of 800 volts D. C. Standard 35 mm. orthochromatic film is used for recording and for purposes of economy each record is limited to one three-foot strip, representing a time interval of ½ second. A clockwork synchronizing mechanism, operated by the speaker just before beginning to speak, switches on the anode potential to the Oscillograph and thus begins the exposure. The exposure is terminated after exactly ½ second interval, corresponding to one revolution of the film drum. This method, which is an improvement upon a method described previously (1), permits of the recording of short monosyllabic or disyllabic words containing several speech-sounds. The film-band can be removed immediately for development and fixing, and it is possible very soon to examine it to determine whether the recording has been satisfactory. Alternatively, a Linear Time-Base-Sweep-Circuit may be coupled to the second pair of deflection plates of the Oscillograph, and will serve to delineate the waveform of the sounds as a fluorescent pattern on the Oscillograph screen. The degree of accuracy in recording over the audio-frequency range with the Cathode Ray Oscillograph is very high. No measurable distortion is observed at frequencies up to 25 kilocycles and possible distortion is introduced only when the speed of recording approaches the finite speed of the electron beam (2). The accompanying reproductions are selected from prints of sections of film records for Northern English vowels and consonants. Certain of the records (identified by the symbols 'Nhb.' for Northumbrian and 'Durham' for County Durham dialects) illustrate dialect pronunciations, while others illustrate Standard English speech-sounds. The records were made by male speakers on an average voice-pitch of about 100 cycles. In this way care was taken to avoid changes in waveform that might result from alterations in voice-pitch. The average voice-pitch in cycles per second is noted at the side of each record. The vowel records are selected to give a representative group covering the vowel-range in Northern English speech.

In a more detailed examination of the records reproduced herewith the most interesting observation is concerned with the manner in which the records may be arranged into groups. The individual records in each group are characterised in having waveforms of the same general pattern. Thus, for example, in Fig. I records 1 and 2 are grouped together, while records 6 and 7 Fig. 1 and records 1, 2 and 3 Fig. 2 form another group characterised by the general waveform pattern of record 7. In Fig. 1 record 5 is in a group by itself, while records 3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Nhb. [wʊ+skɔ·z]
'whiskers'
(118 ∼)
oː
Durham [ɹoːd]
'road'
(128 ∼)
ɔː
St. E. [bɔːd]
'board'
(116 ∼)
əː
St. E. [bəːd]
'bird'
(105 ∼)
ʌ
St. E. [hʌt]
'hut'
(110 ∼)
aː
St. E. [paː]
'pa'
(116 ∼)

Fig. 1.

and 4 are grouped together and illustrate the development towards the type of record 7 Fig. 1. Record 5 Fig. 2 illustrates a waveform of the same general type as that of record 3 Fig. 2. Record 4 Fig. 2 illustrates the development towards the waveforms for records 6 and 7 Fig. 2. This system of grouping is not fortuitous. The waveforms are repeated in records of the same sound pronounced by different speakers, though naturally the individual records show minute differences corresponding to individual qualities of voice. Even before any mathematical analysis of the records has been attempted, it has proved possible to arrange and classify the vowel records on the basis of these similarities and differences in waveforms. It is therefore easily possible straightway to recognise the identity of a vowel record by a comparison of the waveform with these patterns. It is further a significant fact that a close relationship can be traced between the natural grouping of these Oscillograph records and the physiological factors governing the pronunciations of the sounds recorded. The writer has made a careful study of all available speech records made by whatever means by Crandall, Fletcher, Lenk, Scripture et alia, and he finds a substantial degree of similarity between these records and his own Oscillograph records for the same vowels. The available physiological knowledge of the conformation of mouth and throat cavities and the laryngeal positions for the pronunciation of vowels has been recently greatly supplemented by the X-ray photographs of the mouth and throat, published by Russell (3). Though the most satisfactory results would be obtained from a study of simultaneous Oscillograph records and X-ray photographs of the mouth and throat for the pronunciation of each sound, yet the physiological evidence is so striking that it must apply almost universally to the study of the same speech-sound pronounced by many individuals. It is impossible, however, within the limits of this article to consider in detail the available evidence, and, moreover, many more records must be taken before definite statements can be made on the distinctions between vowels. Therefore, the writer limits the present discussion to the proposal of a set of working analyses, which demonstrate in what manner the Oscillograph records substantiate the physiological evidence.

Perhaps the most remarkable group of Oscillograph records is that illustrated by records 6 and 7 Fig. 1 and records 1, 2 and 3 Fig. 2. In this group the typical waveform is best illustrated by record 7 Fig. 1, and record 1 Fig. 2. Physiological evidence and observation show that, when these vowels are being pronounced most clearly and with the greatest intensity, the mouth cavity assumes a funnel or megaphone-shape, widening out from a constricted neck at the Epiglottis, just above the upper opening of the larynx, to a wide opening at the spread lips. The typical Oscillograph waveform for this group is that which approximates closest to a "damped sine curve." Mathematical analyses, whether by Fourier (Harmonic) or Vercelli (Inharmonic) methods, and made by various investigators, show that the components of the waveform are numerous and of fairly regular amplitudes. There appears to be no prominent, strong component. The waveform pattern is very similar to that produced by exciting a strongly-damped vibrating reed or strip and would compare with the waveform of a "puff note" or "edge-tone." The writer is inclined to believe that this waveform approximates closest to the waveform of the vibrations stimulated at the larynx, without the addition of the throat and mouth cavity resonances. The funnel-shaped cavity produced in the mouth and throat would explain why these vowels in particular are the most sonorous and intense vowels in Modern English. Modifications of the mouth conformation, characteristic of the pronunciation of this group of vowels, are generally caused by movements of the tongue in raising towards the palate. A raising of the blade of the tongue towards the hard palate modifies the vowel in the direction of the pronunciation illustrated by records 2 & 3 Fig. 2. A raising of the back of the tongue towards the soft palate and uvula modifies the vowel in the direction of the pronunciation

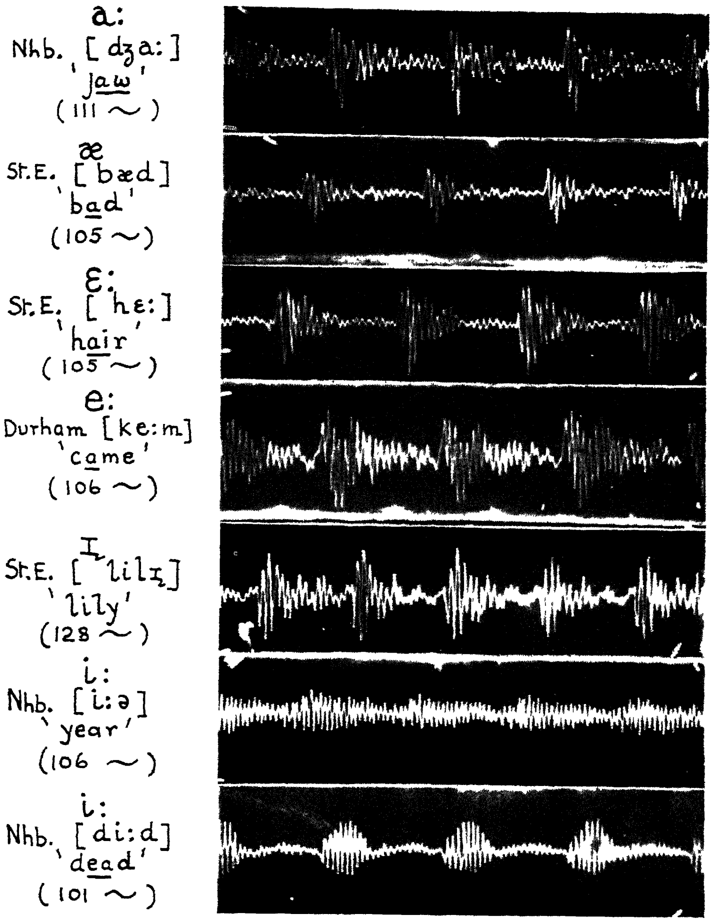
a:
Nhb. [dʒa:]
'jaw'
(111 ~)
æ
St.E. [bæd]
'bad'
(105 ~)
ɛ:
St.E. [hɛ:]
'hair'
(105 ~)
e:
Durham [ke:m]
'came'
(106 ~)
ɪ
St.E. [ˈlilɪ]
'lily'
(128 ~)
i:
Nhb. [i:ə]
'year'
(106 ~)
i:
Nhb. [di:d]
'dead'
(101 ~)

Fig. 2.

illustrated by record 6 Fig. I. and eventually by records 3 & 4 Fig. I. These modifications provoke characteristic modifications in the waveforms recorded by the Oscillograph. The vowel illustrated in record 2 Fig. 2. is generally described in acoustic distinctions as having a "metallic, or ringing" quality. This is most probably due to an accentuation of an upper component in the sound and may be illustrated by the increased amplitude of the high-pitched component in the waveform recorded. Conversely, the vowel illustrated by record 4 Fig. I. is generally described as having a "hollow, dull" quality. This would most probably result from the stimulation of a lower component in the sound and be illustrated by the increased prominence of a low-pitched component in the waveform recorded. These modifications are relative to the pattern recorded in record 7 Fig. I.

The next interesting group of records includes the waveforms for the so-called "back vowels", illustrated by records 1, 2, 3 & 4 in Fig. I. The results of analyses made on the waveforms for these and similar vowels, recorded by other investigators, are in general agreement. Thus for the vowel illustrated by record 1 the analyses show a prominent, low-pitched component, generally at about 300-600 cycles, modulated by an upper component at about 800-1000 cycles, and frequently a weak, high-pitched component at 2000 cycles or higher. In records of a clear voice pronouncing this vowel the waveform is quite simple and consists of the two low-pitched components only. Physiological evidence indicates that for the pronunciation of this vowel there is a narrow constriction between the back, humped-up part of the tongue and the uvula. This narrowing, in effect, separates off the oral passage into two cavities joined by a narrow opening, and having vent to the outer air through a narrow opening at the lips, which are "rounded" or closely approximated. The Oscillograph records indicate consistently that the components of the waveform are overtones of the fundamental voice-pitch, and it appears likely that in this case the components are the cavity resonances stimulated according to the normal laws for such resonances. Moreover, a further interesting observation is that, for the pronunciation of the vowels illustrated by records 2, 3 & 4, the area of constriction in the throat retreats closer to the larynx area, and the back of the tongue is lowered progressively in the mouth. Ultimately, this process of lowering the tongue-position results in an approximation to the position for the previous group of records discussed above. In accordance with this change in the mouth and throat conformation the waveforms of the sounds recorded are modified in the direction of the waveform typical of record 7 Fig. I. This development is, of course, most noticeable in the case of record 4, and the transition in pronunciation from the vowel of record 4 to that of record 7 is easily accomplished in Modern English. From the physiological standpoint the characteristic factor appears to be the progressive retreat of the area of constriction towards the larynx, resulting eventually in a narrowing between the Epiglottis and the pharynx wall. If we accept the view that the component tones are the result of stimulated cavity resonances, then the analyses of the waveforms are consistent with the physiological evidence. Thus, for example, for record 3 the main component has risen in pitch to about 720 cycles and the upper components are more prominent. This is consistent with the fact that the volume of the throat cavity is reduced, accordingly resulting in a higher-pitched natural resonance.

Record 5 Fig. I. illustrates a waveform that stands more or less distinct from the waveforms included in the two groups already discussed. The writer is of the opinion that this vowel and the associated, similar vowels may well form a group by themselves, fairly closely associated, however, with the type of record 6. The short vowel corresponding to the long vowel illustrated in record 5 is the most frequent vowel in Modern Spoken English. It is the so-called "indefinite" vowel and is the type of vowel to which most of the Modern English vowels de-

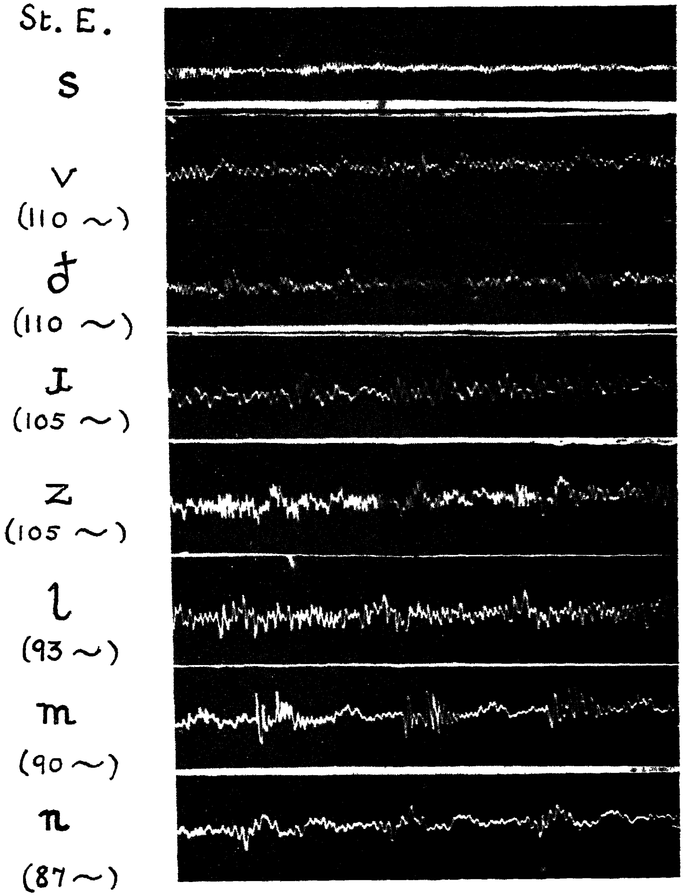

Fig. 3.

generate in hurried and careless speech. Oscillograph records show that the waveform is variable in pattern. The physiological evidence indicates that for the pronunciation of this vowel there is no narrow constriction in any area of the mouth and throat. It would appear that for the pronunciation of this vowel the tongue and other parts of the speech-system assume those positions, *which are most often taken up in a period of relaxation* and rest. The blade of the tongue is slighty raised in the mouth, thus giving to the mouth and throat cavity the shape of a curving tube of fairly-constant diameter, but provided with walls of varying firmness of material. It is, as it were, the easiest vowel to pronounce in the sense that the speech-organs have to execute the least changes from the normal positions of rest. Accordingly, one would would expect a variability in waveform for these vowels, and indeed the Oscillograph records substantiate this.

The final group includes records 4, 6 & 7 Fig. 2 and record 3 Fig. 2 (also considered above in the first group) with record 5 Fig. 2. In this group may be traced two subdivisions, which include on the one hand records 4, 6 & 7 and on the other hand records 3 & 5. From quite early times phoneticians have described an acoustic distinction of quality between on the one hand the vowels in Standard English "pet" and "pit", and on the other hand the monophthongised vowel in Northern English "came" and the vowel in Standard English "seed". The vowels in "pet" and "pit" were often described as "lax", while those in "came, seed" were described as "tense". The Oscillograph records show that some such group distinction can be made between the waveforms for these vowels. Moreover, a great deal of physiological evidence on this point has been gathered by Russell(4). The acoustic distinctions are substantiated to a certain extent by the physiological evidence adduced from X-ray photographs and laryngo-periscopic observations and photographs. It is obvious that, even if the resonances stimulated in the front mouth cavity produced by a narrowing between the tongue and the hard palate and teeth ridge for the pronunciation of the vowels illustrated by records 4, 6 & 7 were very powerful, some change must have taken place in the mode of vibration of the larynx. Apparently, for the pronunciation of these vowels the lower vocal cords are tensed, the ary-vocales muscles are tightened and the ventricular bands are well separated and drawn back to prevent any modifying influence they might exert. The laryngeal sinuses are spread open and the Epiglottis is folded back against the root of the tongue. All these factors render it probable that the larynx is stimulated into a mode of vibration that accentuates the upper partials of the fundamental frequency. Accordingly, in this way the initial stimulus would be supplied to excite the resonances in the front mouth cavity and of the cavity walls. For the records of very tense "front" vowels analysed by Gemelli(5), the frequency of the upper component may be as high as 4688 cycles. In the writer's own experience with Modern English vowels the higher components do not rise much above 3000 cycles for vowels of the type of records 6 & 7. This is probably associated with the acoustic distinctions in quality between the English and Italian vowels, whereby the Italian vowels are described as being "more tense" than the English equivalents.

Conversely, in the case of records 3 & 5 the physiological evidence indicates that for the pronunciation of these vowels the laryngeal area is changed from the conformation assumed for the pronunciation of the vowels in records 4, 6 & 7. For records 3 & 5 some low-pitched component has noticeably modified the waveform from that for the records 6 & 7. This may result from the possible action of the Epiglottis in humping back against the pharynx wall and thus partially interrupting the free outlet from the laryngeal cavity. Moreover, the upper vocal cords, or ventricular bands, may press down upon the edges of the true vocal cords and restrain their action. Laryngo-periscopic photographs show that this may regularly occur. These factors have a modifying influence upon the laryngeal sound and such modifications would become manifest in the waveform of the sounds recorded.

As far as concerns the closer mathematical consideration of the Oscillograph records the writer would like to point out that the majority of investigators agree that an accurate analysis of all vowel components is not possible on a system of Fourier harmonic analysis. In the writer's experience the waveforms illustrated by records 1 & 2 Fig. I. respond best to such analysis. In particular, in the record 1 the two main components are found regularly to have an harmonic relationship with the fundamental voice-pitch. Thus, for example, with a normal voice-pitch of 128 cycles the low-pitched component corresponds to a second overtone at 384 cycles. For a voice-pitch of 180 cycles the low-pitched component corresponds to the first overtone at 360 cycles. For a voice-pitch of 256 cycles the component rises to the first overtone at 512 cycles. Conversely, the upper components are more variable and do not always bear harmonic relationship to the fundamental voice-pitch. The waveforms illustrated by records 6 & 7 Fig. I. and record 1 Fig. 2 prove the most difficult to analyse. Record 7 Fig. 2 illustrates the waveform for a very tense variety of this vowel and the waveform is very characteristic. It is probable that some considerable damping is exerted, especially in the latter half of the waveform. The main component is at about 2550 cycles. Obviously at such a high pitch the component may well vary from one overtone to another of a fundamental voice-pitch of 101 cycles or may be inharmonic. Conversely, in those records for which a low-pitched component can be analysed (viz. records 1 & 2 Fig. I. and records 4 & 5 Fig. 2) the component is generally in harmonic relationship with the voice-pitch.

Several illustrations of records for Standard English consonants are given in Fig. 3. It is to be noted at once that in the records for consonants the component frequencies are generally more variable and of higher pitch than those for vowel records. This is clearly shown in the illustrations of records 1 & 3. The component frequencies may be as high as 4000 or 5000 cycles. Attempts at an analysis of these consonant waveforms do not yield very satisfactory results and it must be remembered also that a considerable range of variation may occur through the length of a record for a maintained consonant of the type illustrated by records 1, 3 & 4. The records for nasal consonants, illustrated by records 7 & 8, show a greater uniformity in waveform and the general pattern is remarkably similar for records of nasal consonants and vowels.

The Cathode Ray Oscillograph and its attendant microphone and recording units form part of the equipment, of an Experimental Phonetics Laboratory, established in Armstrong College in March 1934. The institution and equipment of the Laboratory have been described in more detail previously(6). The Cathode Ray Oscillograph was demonstrated by the writer at the 24th Annual Exhibition of Scientific Apparatus held by the Physical Society in London in January 1934. The institution of this Laboratory marks the culmination of a period of investigation into Experimental Phonetics pursued by the writer over a period of two years. The investigation is being continued with the assistance of a grant to the writer from the Research Committee of Armstrong College, to whom the writer would like to express his sincere gratitude. He would like further to acknowledge his indebtedness to Dr. W. L. Renwick, Professor of English, for his continued support since the beginning of the research; to Dr. W. E. Curtis, F.R.S., Professor of Physics, for his generous assistance both in the obtaining of apparatus and the use of laboratory facilities; and to Mr. Orton of the English Department and Dr. Richardson of the Physics Department for advice and encouragement. The future work of the Laboratory will be concerned mainly with the recording of the speech-sounds current in the local dialects and in Standard English, and with the investigation into the scientific basis of Practical and Experimental phonetics.

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List of unpublished Theses received by the Librarian of Armstrong College during the Period July 31st, 1932, to July 31st, 1933.

Theses for Ph.D.

"Report on the Dytiscidæ."—Joyce Omer-Cooper.

"Part 1. The Polysulphides of the Alkali Metals. Part 2. On the Formation and Existence of the Free Hydroxyl Molecule."—T. G. Pearson.

"The Phylogeny of the British Members of the Dactyl Orchis Group."—M. M. Richardson.

"An Investigation of the Chemistry of Rhenium with Special Reference to its Simpler Compounds."—A. J. Rudge.

"Part I. The Polysulphides of Barium and Calcium. Part II. The Picrolonates of the Alkaline Earth Metals. Part III. Some Physical Properties of the Hydrides of Selenium and Tellurium. Part IV. A Study of the System Phosphorus—Selenium."—W. E. Scott.

"Bicyclic Nitrogen Ring Systems with Special Reference to the Chemistry of Lupinine."—G. R. Ramage.

"Part 1. The Cytology of a Fertile Interspecific Brassica Hybrid." Part 2. The Cytology of a Sterile Interspecific Digitalis Hybrid. Part 3. Chromosome Numbers in the Lepidoptera and their Bearing on Phylogenetic Investigations."—H. C. Regnart.

"Part 1. Some Aspects of the Chemistry of Rhenium. Part 2. The Production of Free Radicles and Atoms by Thermal Dissociation."—E. M. Stoddart.

Thesis for M.A.

“Virgil’s Philosophy.”—E. C. Jones.

Theses for M.Sc.

“Part 1. The Organic Constituents of Ivy. Part 2. Attempts to synthesise a Three Membered Ring containing Nitrogen.”—P. Lunam.

“Part 1. The Structure of Di-isoeugenol. Part 2. The Constituents of Guaiacum Resin: a Synthesis of Pyroguaiacin Methyl Ether. Part 3. Some Orientation Experiments.”—C. R. Mavin.

“Part 1. Ring Closure Studies in the Piperidine Series. Part 2. Attempts to synthesise 9-Substitution Derivatives of Dekahydronaphthalene.”—John Ormston.

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“General Survey of the Primulas of the Vernales Section with Special Reference to *P. Elatior* and its Allies.”—M. Watson.

“Part 1. The Reaction of Hydrogen with Selenium. Part 2. The System Phosphorus-Selenium.”—J. M. Baker.

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“Studies in Binary Nitrate Systems containing Lead Nitrates.”—H. M. Glass.

“The Motion of Solids of Revolution in Three Dimensions, and Infinite Symmetrical Cylinders in Two Dimensions, through a Liquid . . . .”—John Masterman.

“The Testing of Coal for the Gas Industry.”—Lilian Wallis.

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“The Problem of Inflation in Relation to the Present World Depression . . . .”—W. A. Tweddle.

LIST OF
PAPERS READ DURING THE SESSION.

1933.

Dec. 6th—" Rule and End in morals." A discussion.

,, 14th—" Recent developments in infra red photography" by Mr. Darbyshire.

1934.

Jan. 17th—" The limits of Purpose" by Miss D. M. Emmet.

,, 22nd—" Animal locomotion" by Dr. Jas. Gray, F.R.S.

Feb. 5th—" Hydrodynamic Experiments with Ship Models" by Dr. Todd.

,. 12th—" Evolution in the Expanding Universe" by Abbe G. Lemaitre, Sc.D., Ph.D.

,, 21st—" Scientific Aspects of Phonetics" by Mr. R. O. L. Curry, M.A.

,, 27th—" Recent Developments in the Chemistry of Phenanthrene" by Dr. R. D. Haworth.

Mar. 12th—" Metallographic Examination of a Roman Chisel" by Mr. C. E. Pearson, M.Met. & Dr. J. A. Smythe

,, 12th—" A note on an early experiment in Industrial Conciliation" by Mr. E. Allen, M.A.

,, 13th—" Quantum Mechanics" by Mr. J. F. Wood.

Apr. 26th—" Observations on the Flow of Metals during Extrusion" by Mr. C. E. Pearson. M.Met.

May 25th—" The classification of Carboniferous — Permian igneous rocks" by Mr. S. Tomkeieff.

,, 25th—" The microspores of some Lower Carboniferous coals" by Dr. A. Raistrick.

Oct. 25th—" Proceedings at the International Conference on Physics" by Professor Curtis.

Nov. 22nd—" The Present State of Mathematical Philosophy" by Mr. M. Black.

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LEAD SMELTING IN THE NORTH PENNINES DURING THE 17TH AND 18TH CENTURIES

by

A. RAISTRICK, Ph.D., M.Sc., M.I.Min.E.

The area indicated in this title is the drainage areas of the Tyne, Wear, and Tees, with the Westmorland scarp of the Cross Fell massif. Very few records of lead smelting have persisted from the period prior to 1700, except in the form of extensive 'slag heaps' associated with Balehill sites. We know that during the sixteenth century the German miners introduced the continental type of furnace for copper and lead smelting at Keswick, and that shortly afterwards, they were in contact with the miners of north Yorkshire, who soon adopted a modified German furnace, or orehearth, as their principal means of smelting. The records of this period however are too scattered to allow a consecutive story to be written.

The continuous records of smelting operations through the 18th and 19th centuries, in the north, begin with a smelt mill at Ryton-on-Tyne, built by the 'Ryton Company' about 1696, under the direction of Dr. Edward Wright and his partners. Dr. Wright was a physician and chemist, at "the sign of ye Shipp, nere ye Monument in London," a member of the Society of Friends (Quakers), and a student of metallurgy. In association with Jacob Ffreame, a goldsmith of London, and John Haddon a mechanic, he had taken over from the German miners, some rights in the charter of the Society of Royal Mines Copper, under which copper ores had been mined and smelted in Cumberland and Westmorland during the late 16th and 17th centuries, and had experimented with many improvements in the furnace commonly in use. Sometime before 1692 he had evolved a "cupola" or reverberatory furnace and in addition to applying it to the smelting of copper, had experimented with ores of lead, and with a process of extraction of silver from silver-lead. The work at Coniston and Little Langdale in the Lake District, was gradually transferred to a site in North Wales, Gadlis near Flint, and to Ryton-on-Tyne, some of the ores from Caldbeck, Cumberland being sent to Ryton, and Welsh ores purchased for Gadlis.

In 1692 William and Mary granted a charter of incorporation to Vernatti and several other adventurers, as the " Governor and Company for Smelting down Lead with Pitt Coal and Sea Coal," and for a few years they smelted lead at Bristol, but with no great success, finally allowing the company to lapse and selling the works in 1695, (for a full account of this Co. see Raistrick. Trans. Newcomen Soc vol. xiv. 1934. The London Lead Co.) Their charter prevented Wright from extending his reverberatory furnace to the smelting of lead In 1696, Wright and Haddon, and a number of Newcastle Friends became shareholders in the Ryton Company, with a small smelting plant on the banks of the Tyne at Ryton, working up ores purchased among the mines of ' Aldstone Moor.' In 1704 Wright, Haddon and Ffreame, were able to effect the transfer to themselves of the charter of the " Governor and Company for Smelting Lead, etc " and the old Society of Royal Mines Copper, and the Ryton Company were both merged in the Governor and Company, to form what became better known as the London Lead Co. From 1704 to 1900 the L.L.Co. was the largest lead smelting and silver refining agency in the north of England.

The Ryton ' Cupola ' in 1704 had three ore furnaces, a reducing furnace, two refining furnaces, and a slag hearth, the process employed being to smelt the ore directly in the three ' cupolas,' to refine the lead so obtained by conversion to litharge in the refining furnace, with isolation of the silver, then to resmelt the litharge in the reducing furnace, treating the bone-ash " test bottoms " and the slags together in the slag hearth. The scale of the plant may be indicated roughly by its production of about 350 ozs. of silver per month. At an early stage in development an attempt was made to find markets for some of the litharge and save cost of reducing.

The L.L.Co. quickly adopted the policy of owning its own mines, and supplied the ore to Ryton from a group of mines at Tynehead, Ashgill, and Blagill, in the S. Tyne and Nent valleys. In 1706 the " old mill " at Whitfield, in the junction of the East and West Allendales, was leased, and the smelting of Tynhead ores transferred to it, a new set of furnaces being constructed. The Ryton Mill was sold at a later date to the Blacketts (later the Beaumonts), but the wharfe on the Tyne at Ryton (Stella) was retained until 1836 as the principal loading staithe for the Cos. lead and silver.

In 1708 the Co. took leases of a group of mines near Blanchland, the Shildon, Redgroves, Jeffries, etc., and built a smelt mill to serve them, on the upper part of Acton Burn, the mill remaining in work until 1806 when it was dismantled. This mill was like the Whitfield and Ryton mills, in its use of the cupola type of furnace, both for smelting and refining lead. As the Derwent mines expanded an old smelt mill at Jeffries (Hunstanworth) was leased and reconditioned and dealt with all the ores of the Jeffries, Whiteheaps, area. This mill was put in work in 1710 and remained in the hands of the L.L.Co. until 1808, when after a short rest it was again put in commission by the L.L.Co's. successors and only finally dismantled in 1883.

The next important group of mills is that belonging at first to the Blacketts and later to the Beaumonts, in Allendale and Weardale. These were in full work before 1725 and accounts of their work and output are available from 1730 to 1840 without break. In Weardale the mill at Rookhope was apparently getting old and inadequate, as it was closed before 1740 for reconstruction. It was equipped with ore hearths and simple blast hearths, the use of the ' cupola ' being restricted at first to the mills of the L.L.Co., only later being adopted by other smelters for the refining of lead. The output of Rookhope was about 1500 bings (of 8 cwts) per annum, dwindling rapidly between 1735 and 1738. As this mill was put out of action, a small mill was built at Lintzgarth, to take its place, and until 1750 was smelting amounts varying between 1000 and 2000 bings per annum, continuing to deal with all the ores that previously had gone to Rookhope. The new Rookhope mill was put in work at the end of 1750 and in 1757 showed a marked increase in work, jumping from an average output of about 2000 bings to about 4800 bings, and in 1780 increasing again to about 7500 bings. This mill remained the chief smelting place for the ores from the Beaumont mines in Weardale until 1883, when it passed to the Weardale Lead Co., and by them was continued in use well into the 20th century.

In Allendale a mill was built at the beginning of the 18th century, near Allenhead, remaining in commission until 1870. This mill mainly smelted ores from Allenhead and Coalcleugh mines but was kept working to capacity (about 1200 bings) by ores from the highest of the Weardale mines. As in all the Beaumont mills the furnaces were of the ore-hearth type, with a blast supplied by a water wheel and bellows. A third smelt mill situated on the Devils water near the hamlet of Steel, is the Dukesfield mill, built prior to 1728 and being the largest of the Beaumont mills. This mill received ore from all the Blackett and Beaumont mines, and had a working average output of about 2000 bings per annum, increased in 1750 to over 3000 bings, and in 1780 to 8000 bings. In 1770 Dukesfield mill was extended by the addition of refining furnaces, and from then to its demolition in 1837 it continued to receive quantities of smelted lead from Rookhope and the Allendale mills, for the extraction of silver. In 1795 an old and derelict mill, near Allendale town, the Allen mill, was remodelled and put in work both smelting ores, and refining lead. Its capacity was about 5000 bings per annum.

Throughout the period of the Blackett and Beaumont mines, the chief refining centre had been at Blaydon (parish of Ryton) where the old Ryton Co's. mill had been considerably extended after 1725 and adapted for the lead sent in from the other mills. It was at Blaydon that

Pattinson worked as chief smelter and assayist, when his process of silver extraction was evolved.

To return now to the L.L.Co's mills; three important smelting centres were added to their concern during the 18th century. The first in 1746 was the mill at Nenthead, for dealing with the local ores from Nenthead, Ashgill, and Tynehead, though for a time some of these ores still went to Whitfield, this mill remaining one of their most important until 1882. Like the earlier ones it was equipped with reverberatory furnaces both for smelting and refining. A small mill was leased and later purchased, at Egglestone near Middleton in Teesdale, the lease being taken up in 1789. In 1800 this mill became the scene of an important and far reaching set of experiments on smelting technique, and with the development of new methods and the extension of mining leases in Teesdale, the mill was triplicated, as the High, Middle, and Low Mills. In 1801 the L.L.Co. leased Stanhope mines and mill in Weardale and at once replaced the old ore hearths by reverberatories. When the Acton and Jeffries mills were surrendered in 1808 the newly fitted Stanhope and Egglestone mills replaced them, with a slightly higher smelting capacity. The Stanhope mine boundaries were the subject of a dispute in the period 1840-46 and in the settlement the L.L.Co. surrendered all mines in the Bishop of Durham's ground, in exchange for the Bollihope Burn area of leases. The old smelt mill on the Bollihope Burn was reconditioned and extended, though much of the Weardale ore was now taken to Egglestone.

Most of the mineral ground of Alston Moor had been in the possession of the Earl of Derwentwater who was executed after the Jacobite rising of 1715, and was forfeited to the Crown, being granted out to the Commissioners of Greenwich Hospital in 1734, as an augmentation of their estates revenue. The Greenwich Hospital had granted most of the mine leases to the L.L.Co. between 1745 and 1750 at a ' duty ' of 1/5 of all the ore got. For many years the Hospital agents sold the ore by auction on the Moor, it being bought in generally by the Co. that had raised it, a simple way of converting the duty ore into cash value, but in 1767 they decided to smelt their own ores, and to do this built the Langley Mill, near Langley Castle. This rapidly became a very important mill, remaining in Greenwich Hospital hands until 1833 when it was leased to a private company, being finally dismantled in 1887. The site of this mill was chosen with reference to the small Stubblick coalfield, only half a mile away, and to the main Allendale road, linking it with all parts of Alston Moor. This road was in fact promoted jointly by the Hospital and the L.L.Co. The mill obtained all its necessary fuel from the adjacent coalfield, with the minimum of carriage. A similar relationship is seen at many other of the smelt mills; the lease of Whitfield mill included the Coanwood Colliery, a small group of coal pits on the south border of the Plenmellor coalfield. Nenthead mill used part coal from Coanwood and part from several small mines in the local Little Limestone coal; Egglestone and Stanhope drew their coal from mines mainly in the Millstone Grit coals of the fringe of the Bishop Auckland coalfield. A report on the Beaumont mills in 1808 reveals many interesting facts both with respect to coal supply and roads within their area. The coal for Rookhope mill was carried by pack-horses from Medomsley, and for Dukesfield and the Allendale mills, it was carried from the Greymare Colliery (south west of Whittonstall, on the summit of the hills between Ridingmill and Shotley Bridge), though later part of this coal was taken for some processes to Rookhope. The packhorse leaders were not strictly honest as the following extract will show. " Many of the carriage men took the coals from the pit in Cart loads and laid them down at their own houses after which they filled them into Sacks of very different sizes some making the fother into 10, others into 12 Sacks, and sometimes a greater number just as their Sacks were of size, the price of the Coals, and for the Carriage being charged at the Mill by the Sack or load they were in many instances paid for Coals that were never delivered," etc. A uniform sack of three Winchester bushels was adopted and careful checking at the mills quickly introduced more regular coal costs. It is noted on more than one occasion that the

Medomsley coals are hotter and make a better lead than those from Greymare, but the difference in distance of carriage just about equalised their value.

In addition to these larger mills there were a few smaller mills in the area, which deserve mention for the sake of completeness. The L.L.Co. in 1801 took leases of mines and built smelt mills at Hilton and Dufton on Crossfell edge, Westmorland, while the Beaumonts for a few years about 1834 rebuilt an old mill at Blagill in the Nent valley, and about 1743 built a mill at Burtreeford, Weardale. The Earl of Darlington who owned much of the mineral ground in Teesdale had his mill for smelting ' duty ' ore, on the R. Gaunless, tributary of the Wear S.W. of Bishop Auckland. A mill was built at Healeyfield, near Consett in 1805, and this for nearly a century smelted ores from the Healeyfield mines and from many other minor sources, changing over in 1913 to the smelting of lead residues. A small mill existed prior to 1680 at Feldom near Edmondbyers, which was taken over by the L.L.Co. in 1725, but dismantled a few years later. It has not been possible to obtain as yet, any record other than the tradition of the Langdon Mill, Teesdale. No figures are now available for some of these smaller mills, but their contribution can never have formed more than a very small fraction of the output of the area. The duration and relative size of the mills can best be shown in tabular form.

The progress of Lead Smelting.

At the opening of the 18th century practically all lead smelting was carried out in the orehearth, which was essentially a furnace modelled on those described by Agricola and used by the Germans in the Lake District in the 16th and early 17th centuries. A drawing in the Egerton MSS, British Museum* illustrates the ore hearth as used by the Mine Adventurers of England and others in Yorkshire, in 1735, giving all the details of the furnace and tools, and tallies in all respects with that in general use in the North of England during the 18th century.

*reproduced in Raistrick, A. Lead Mining and Smelting in West Yorkshire. Trans. Newcomen Soc. vol. vii. 1927. plt. xv.

LIST OF SMELT MILLS IN THE NORTH PENNINES.

	Name of Mill.	Owner.	Opened	Closed	a	b	c	d	e	f
1.	ACTON	London Lead Co.	1710	1806						
2.	BOLLIHOPE	,, ,, ,,	1846	1880						
3.	DUFTON	,, ,, ,,	1801	1847	4					
4.	EGGLESTONE HIGH	,, ,, ,,	1771	1903	2	1	1	2	1	
5.	,, MIDDLE	,, ,, ,,	c 1800	1903	3	1		2		
6.	,, LOW	,, ,, ,,	c 1800	1903	2	1	1			
7.	HILTON	,, ,, ,,	1801	1870	4		1	1		
8.	JEFFRIES	,, ,, ,,	1713	1870						
9.	NENT HEAD	,, ,, ,,	1746	1882		4	4	2	1	1
10.	RYTON	,, ,, ,,	1696	1706		3		2	1	1 (1706)
11.	STANHOPE	,, ,, ,,	1801	1880	3	3				1
12.	WHITFIELD	,, ,, ,,	1706	1816						
13.	ALLEN	Beaumonts	1692	1896	5		2	2	1	
14.	ALLENHEAD	,,	pre 1725	1870	3		1			
15.	BLAYDON	,,	,, 1725	1870				4	2	1
16.	DUKESFIELD	,,	,, 1725	1834	5		2	2	1	2
17.	ROOKHOPE	,,	,, 1725	1883	3		1			1
18.	LANGLEY	Greenwich Hospital	1767	1887	10		5	4	2	
19.	BLAGILL	London Lead Co.	1704	1736						
		Beaumont	1833	1840						
20.	BURTREEFORD	Beaumont	1743	1750	2					
21.	CROSS FELL	Cross Fell Mine Co.	1804	c1840	2					
22.	EDMONDBYERS	J. Joplin			2		1		1	1
23.	FALLOWFIELD	Walton & Cowper	1840	1847						
24.	FELDON	Various and L.L.Co.	1680	1730						
25.	GAUNLESS	Earl of Darlington	c 1770	1870	3	2	1	2	1	
26.	HEALEYFIELD	Healeyfield Mines Co.	1805	1913	2		1	1	1	
27.	LINTZGARTH	Beaumont	1736	1750						
28.	TYNEHEAD	J. Lowry	c 1790		2				2	1

a. Ore hearths.
b. Cupolas.
c. Roasting furnaces.
d. Refining furnaces.
e. Reducing furnaces.
f. Slag hearths.

Equipment figures given for 1820 unless otherwise stated.

Wrights' improvement on this was the building of a reverberatory furnace, in which it was possible not only to smelt cleaner lead with economy of fuel, but to handle larger quantities at a charge. For refining also the reverberatory was superior to the old type of furnace, and a report about 1706 shows that the ' cupola ' could extract " near half as much again " silver from the lead, as the old " hearth." Experimental work was given a very prominent place in the policy of the L.L.Co. and between 1704 and 1720, much time was spent on studying three problems in particular, (a) the best temperatures and speeds for casting lead to avoid " that ringing quality " that was disliked by the merchants; (b) the design of chimneys to give the best draught regulation and furnace temperature; (c) the manufacture of bone ash ' tests ' for use in refining lead, and the recovery both of test-bottom and slag leads, leading to the general introduction of a modified furnace, the ' slag hearth.' By 1750 the L.L.Co.

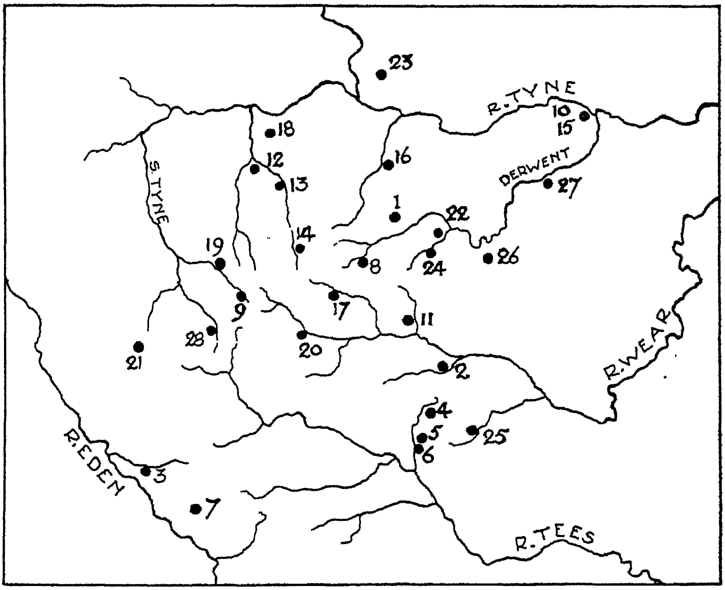


Fig. 1.

were depending far more on their chimney and furnace design, than on the blast from water driven bellows, for the success of their smelting.

In 1778 Bishop Watson writing on Derbyshire Lead Ore in his Chemical Essays, suggested that a considerable amount of lead was sublimated and lost with the smoke or fume of the furnace, and suggested the use of water condensers or horizontal chimneys of sufficient length, to overcome this. The L.L.Co. at once adopted and rapidly developed his suggestion at their mills in Derbyshire and North Wales, and on the building of their Egglestone and Stanhope mills, introduced their long ground level flue between the furnace and chimney base. In 1802 a general instruction was sent to all their mills to provide such horizontal chimneys. The Beaumont mills followed this lead a few years later, the first being built at the Allen mill in 1807, and in 1808 it is reported " the horizontal Chimneys erected here have answered the utmost expectation, my observations upon them I have sent to Mr. Cockshutt but as the extension of them at the other works will be attended with very considerable expense, it must rest with Coll: and Mrs. Beaumont to give directions how far they would wish to adopt them." The general adoption came a few years later, but between 1845 and 1850, under the guidance of Thomas Sopwith, the Allendale chimneys were lengthened beyond any others in the country, having a total run of over 8,000 yards.

In 1796 Robert Stagg was appointed superintendent of all the L.L.Co's. smelting and ore treatment, and immediately initiated experiments at Egglestone, making a strict comparison over a period of years, between the smelting efficiency of orehearth, blast hearth, and reverberatory furnaces for different types of ore, and also on the effects of pre-roasting of ores. The result of this was the general adoption all over the Pennines of the " roasting furnace " about 1805, and the wide extension of the use of the reverberatory furnace for refining and to less degree for smelting. Careful accounts were compiled of fuel used in all processes, and in 1830 a series of detailed tests were made at Langley Mill and Nent Head Mill, to determine the amount of fuel used in the complete treatment of ore and lead. It will be seen from the results, how far the L.L.Co. had advanced in furnace design and fuel economy.

	Fuel used per fother (21-cwt.) of lead produced.	
Process.	Nent Head (L.L.Co.)	Langley (Gr. Hosp.)
Roasting ores	504 lbs. coal	882 lbs. coal
Smelting ores	336 ,, ,,	882 ,, ,,
Refining lead	336 ,, ,,	392 ,, ,,
Reducing litharge	504 ,, ,,	588 ,, ,,
Slag smelting	3864 ,, ,,	2840 ,, ,,

The L.L.Co. adopted generally the practice of mixing some amount of peat with the coal used in smelting, a method first tried out at the Acton mill in 1720, when a lease was taken of peat pits on Slaley Moor, adjacent to the coal mine that supplied their coal. About 1870 the L.L.Co. completed a method of converting peat into a charcoal, and briquetting this for use in the furnaces. A paper on their processes was presented to the Society of Engineers in 1876, and a general account of their work included in the supplement to Dr. Ure's Dictionary of Arts, Manufactures and Mines, 1879.

The L.L.Co's. accounts show a saving of £1,500 per annum per furnace as the result of roasting the ores.

Immediately on the adoption of the slag hearth, the Beaumont smelters had made some advances in the treatment and preparation of slags, and a report by Mr. Mulcaster in 1808 comments on these improvements. " We have now introduced through the whole of Coll: and Mrs. Beaumonts Works the running the Slag from the Slag Hearth into water which has entirely superseded the Stamp Mills, which were attended with considerable expense, another improvement has since been adopted of having the Slagg run over a pott with a moveable partition which does not quite reach the bottom one part of which only is kept filled with ashes as before in which the Lead subsides and rises in the other part of the pott which at the beginning is empty, out of which the Lead is ladled out into the Moulds without the necessity of removing the ashes out of the pott as was formerly done before a piece of Lead could be laced. Since the above alterations have taken place the Black Slags are rendered so poor that we have been under the necessity of doubling the price for the Lead obtained in washing them and rather doubt that it will not be found sufficient, as they are paying much higher at Langley Mill." The slags run into water were finely divided and so made ready for the slag hearth, while the running of lead and slag over ashes allowed the molten lead to filter through the ashes, the viscosity of the slag preventing it doing the same, thus effecting an easy separation.

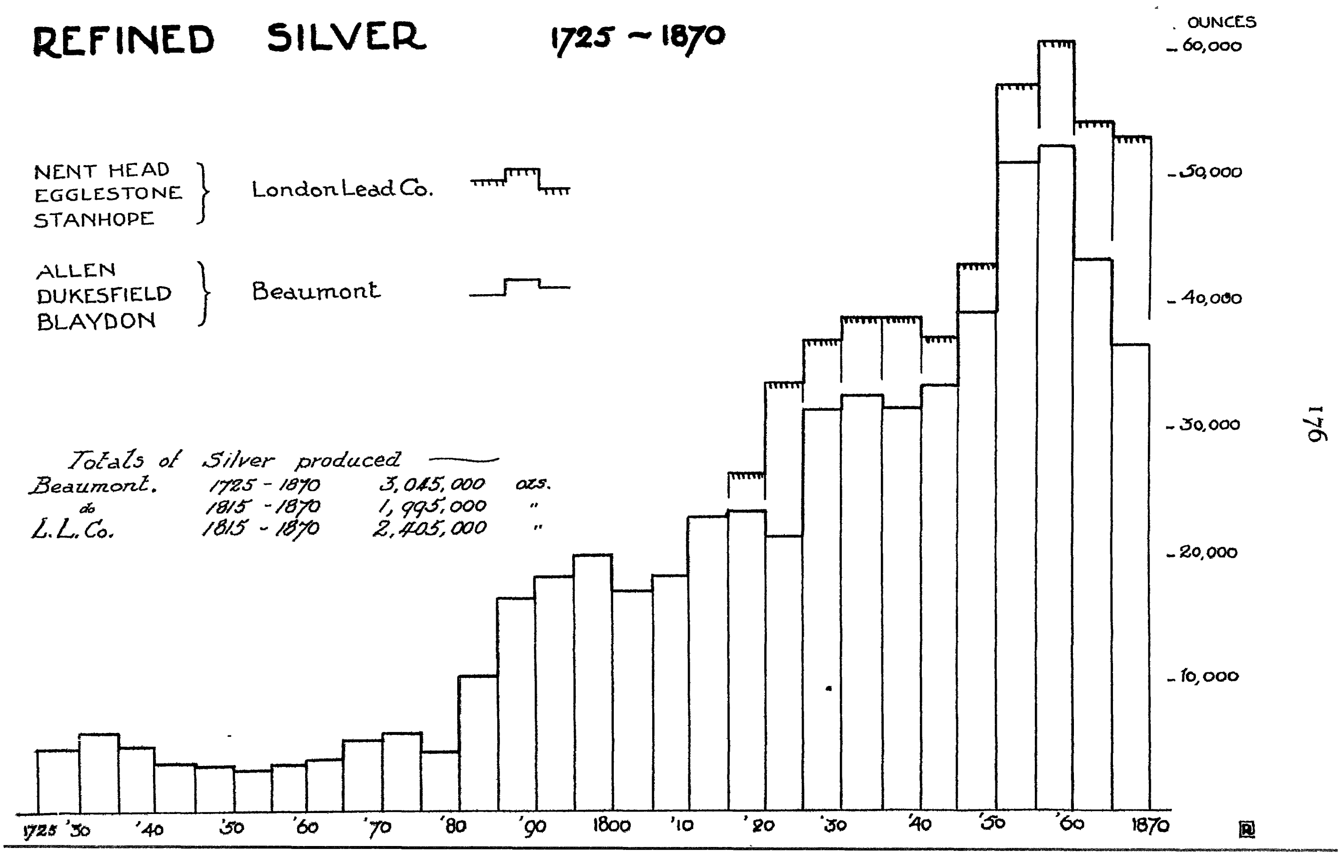
A further note shows the adoption of the L.L.Cos. practice of storing and treating separately the ores from each mine, and using a system of mill stamps and marks so that any piece of lead could be traced back not only to the mill that smelted it, but to the parcel of ore from which it was obtained. This was important as the quantity of silver in the lead varied from vein to vein, and some ores were far more suited for refining than others.

About 1845 the L.L.Co. abandoned the horizontal chimney for the purpose of fume condensation, for the alternative of a fume " condenser " invented by Joseph Stagg, grandson of the Robert Stagg who had carried out so many improvements at the beginning of the century. Stagg's condenser was built at Egglestone Mill, with great success, and then applied at Nent Head with still further improvements. This condenser has been adequately described by Percy in his Metallurgy of Lead, 1870, p. 441. During the 19th century little alteration was made in the furnaces used, except to modify the processes for increased draught. This was partly the result of the greatly extended chimneys, and partly the introduction of blowing engines in place of water wheel and bellows.

Silver Refining.

From the earliest days of the reconstituted L.L.Co. (1704) the prime focus of their attention was on the extraction of silver from the smelted lead. In forwarding this object

REFINED SILVER 1725 ~ 1870



Totals of Silver produced —

Beaumont.	*1725 - 1870*	*3,045,000*	*ozs.*
do	*1815 - 1870*	*1,995,000*	*"*
L. L. Co.	*1815 - 1870*	*2,405,000*	*"*

they searched the country from end to end for mines of lead ore rich in silver and for silver ores. They worked the mines at Wanlock Head and at Stirling in Scotland, for many years, and even sent an expedition from Newcastle, in 1709, to explore and try out reputed mines of lead and silver in the Orkneys. Other ventures included mines in Derbyshire, Wales, the Laxey Mine Isle of Man, and several places in Ireland. Their policy throughout was to make careful selection of ore for refining, and to refine at one operation, ore from only one mine; in this way they knew exactly what yield of silver to expect and what quality of ore they had to deal with, for ‘hardness’ impurities, etc. the mill at Acton was refining Shildon ore with 15 ozs. silver per ton while Ryton, and later Whitfield had as their ‘plum’ the ore from Clargill Head veins with 35 ozs. silver per ton. The smelting was carried out in a ‘cupola’ or reverberatory furnace, and in 1706 a discovery was made that lime could be added to stiffen the slag and increase the ease of handling while in the furnace, and also that the first lead ‘sweated’ from the ore was richer in silver than the subsequent run. This first run was always sent to the refinery and treated separately from the later lead. The refining was done in a slightly modified cupola, and the litharge tapped from the side of the furnace, and generally reduced in a further modified reverberatory. In 1708 however, the L.L.Co. began to put some of their litharge directly onto the market, and a large trade was developed with the glass makers on Tyneside, later continued and extended by the Beaumonts.

The L.L.Cos’. contribution to silver refining was almost entirely their insistence on most careful selection and grading of ore for smelting, and then fractionation of the lead for refining in the reverberatory furnace. This along with due regard to the fuel used, etc., made their silver renowned for its purity, so that for over a century and a half they could claim that their product was “better liked in the market than any other in the Kingdom.” From 1706 to 1737 they supplied large quantities of silver to the Mint, and much of the country’s coinage of that period bears their mark of "two roses and two plumes, quartered" on the reverse.

In 1775 the Langley mill carried out an extensive series of experiments on reduction of litharge, and considerably improved this branch of the work. Many of their results are preserved but are too long for inclusion here. An example will indicate their nature:—"Account of Experiments to Reduce Litharge of Lead, with Charcoal, Coal and Charcoal mixed, and Coal alone as hitherto used:—Nov. and Dec. 1775." etc. etc.

The extraction of silver by conversion of the lead to litharge and subsequent reduction back to lead, was only superseded in 1833 by Pattinson's discovery of a process of physical separation of silver rich crystals from a melt of silver lead. The experiments leading to this discovery were carried out at Blaydon, and some of the correspondence relating to their progress shows that the extension from the laboratory experiment to the commercial scale process was by no means accomplished easily. One letter of April 27th, 1833 says "Mr. Pattinson—as may be expected—has met with more difficulties than he anticipated in his new process. He has made 100 Pces. this week" (pieces of lead of 1¼-cwts.) On August 20th, however a letter states "he is now taking out his Patent, satisfied that it will turn out more beneficial than he at first anticipated," and that it would be possible "to refine from 5 to 6,000 Pces. a month." Pattinson's process was immediately put in operation at the Blaydon refinery, and the L.L.Co. applied for sanction to use it at Nent Head and Egglestone, paying Pattinson £1,050 for the permit. Beaumont, as his employer when the discovery was made, claimed and obtained the right to use the process without charge.

Joseph Stagg, the L.L.Co's. chief smelter, who had built an assay office at Nent Head and Egglestone in 1833, to check all processes daily, claimed in 1840 to have improved Pattinson's process of desilverisation, and to have invented a method which considerably reduced the labour involved. After consultation and agreement with Pattinson a patent was taken out for this improved process. About this time the L.L.Co. sent several of their younger men to Dr. Richardson of Newcastle, to be trained in Chemistry, and in 1850 and 1856 made him presents (£200 on each occasion) for improvements in their processes, and particularly in methods of calcining ores, which they considered were the direct result of training given by him, to the people making them.

With the considerable advantage of the Pattinson process, the L.L.Co. began to buy small quantities of silver rich ores from the Laxey mine, and from Spain, for desilverisation. At the same time a fair quantity of silver rich lead was imported into the Tyne and a new industry—silver lead refining—developed, entirely independent of the local lead mine produce. The L.L.Co. remained throughout the 19th century the largest producers of silver, in the north, reaching their maximum in the period of 1850-1860 with an output of over 60,000 ozs. silver per annum. The graph, (fig. 2) will perhaps indicate the relative growth of both the mining and the silver output, when we remember that the silver produced is roughly proportional to the lead ore smelted.

"RARA AVIS IN TERRIS:"

The Laws and Customs of Lead Mines—in West Yorkshire.

by

A. Raistrick, Ph.D., F.G.S., M.I.Min.E.

The lead mining fields of West Yorkshire may conveniently be regarded as two areas, Swaledale and the north side of Wensleydale; and Wharfedale, with part of Nidderdale and Airedale adjoining. These areas are separated by a broad belt of very much impoverished mineral ground, which includes most of the area of the southern tributaries of the River Ure, and the high moors between Wensleydale and Nidderdale. This natural division is reflected in the entirely separate historical development of the two fields, and to a less extent in the methods of working. The present paper is restricted to the mineral area of upper Wharfedale, with some overlap into Nidderdale and Airedale.

Evidences of Roman mining are well known from the moors between Wharfedale and Nidderdale, not only by actual mining remains, but by the existence of two pigs of lead with Roman inscription, and the record of a third pig. The two pigs still to be seen are inscribed (or rather carry the cast inscription) IMP. CAES. DOMITIANO AUG. COS. VII. which corresponds with the date 81 A.D. while the third is recorded by Lucas (the officer responsible for the Geological Survey of the area 1867-72) as being inscribed with the name Trajan and a date 98 A.D.* In the extensive Romano-British and Iron age "camps" near Grassington, several articles of lead, principally small plates and spindle whorls have been found, some associated with Iron age material of 2nd century B.C., and some with Roman material of early second century A.D., and these are sufficient to prove the early use of lead in the same district.

From the Roman occupation until the establishment of the big monastic houses in the twelfth century, there are no records of lead mining in the area, although some of the names are very suggestive of Anglian interest in the mines; Graeves, Ald Gang, etc., are such names associated with some of the oldest mines. From the thirteenth century onwards, an almost continuous record of mining activity can be traced and documented until the closing down of the industry at the end of the nineteenth century. Not the least interesting feature of this long mining history is the rich contribution made to the traditions and vocabulary of the Dales, and to the customs of the dalesfolk. Among the most persistent memories of the oldest miners, and the still older oral traditions, are stories of the meetings about Easter and Michaelmas of "Barmoot Courts," and of judgments indicating a traditional set of laws similar to those well known from Derbyshire and Mendip. It is only recently that these laws could be documented, although tradition had enabled many of them to be restored. The full laws are contained in a 16 page small 8vo. pamphlet, recently acquired and now in the Leeds Central Reference Library; as these laws are otherwise entirely unknown, and their existence was unknown to all who have written on the mining laws of Derbyshire and Mendip, it seems well that they should now be commented upon, and related to those of other areas. The pamphlet has the following title page:—

Rara Avis in Terris:
or
The LAWS and CUSTOMS
of the
LEAD MINES
Within the Mineral Liberty of GRESSINGTON CUM MEMBRIS, and all other
Mineral Liberties of the Right Hon.
RICHARD Earl of BURLINGTON, in the
WEST-RIDING of the County of
YORK.

By Solomon Bean, Barr-master of the said
Liberty.
LEEDS:
Printed by JAMES LISTER, 1737.

The first section of the pamphlet explains its compilation and agrees entirely with the oral tradition that had previously been collected in the Dale, and that was still remembered a few years ago by the older miners.

Gressington
cum Membris.

To wit. At the Great Court
Barmoot for the
Lead Mines of the Right
Honourable Richard Earl
of Burlington, held at
Gressington, in the West-
Riding of the County of
YORK, for the Mineral
Liberty of Gressington cum
Membris aforesaid, the
second Day of May, in the
Year of our Lord 1737.
Before Samuel Heathcote,
Gent. Steward there.

The names of the Jury to inquire, etc.

Christopher Falshaw
John Slinger, Sen.
John Slinger, Jun.
Thomas Spence
John Coates
George Sawley
Thomas Bocking
James Calvert
William Calvert
John Harrison
Richard Carr
Thomas Calvert

Sworn

William Chapman
Robert Calvert
Robert Jague
Christ. Wharton
John Barras
Francis Slinger
John Calvert
Thomas Tatum
Thomas Sidgwick
John Scot
Christ. Chapman
William Ibbotson

p.4. Wheras great Inconveniences have happened to all Persons concerned in the Mines, within this Liberty, and many Disputes and Controversies have arose, for want of a due Regulation and Understanding of the Laws and Customs, which have Time out of Mind

> prevailed and been used, within the said Liberty, for remedying of such Inconveniences, and preventing Disputes; and for putting the said Laws and Customs upon a proper Footing and Regulation, and that for the future there may be a certain and standing Law of the Mines, within the said Liberty, we do present and say upon our Oaths.

From this point on the Laws follow, numbered I. to XXXIII., the whole being then signed by the Steward, two Barr-masters, and the Jury already given.

The laws may be summarised briefly as follows, and comparisons with those of other mining fields have been added, with the letters D and M, to indicate the Derbyshire and Mendip laws, respectively.

I. "The Lord of the Field (Royalty owner) appointed an officer, called a Bergh-Master, or otherwise a Barr-Master, to be an indifferent Person betwixt the Lord of the Field or Farmer, and the Miners." He gave liberty to sink and try to get Lead Ore, etc., and on any miner finding a new rake or vein, the miner to be granted two Meers of ground in the vein. The Meer is to be 30 yards in length along the vein, and 7½ yards " from the vein sideways in breadth," except in Longstrothdale and Littondale, where it is to be 32 yards along the vein and 8 yards wide. The miner is to pay 1/6d. for the measuring and booking of his ground.

D. The meer is to be 87 ft. along the vein, width not specified, miner to have two meers on discovery of vein.

M. On discovery of vein, the miner to have " his hact throw two wayes after the rake; and note that he that throw hact must stand in his pit or groove to the girdle or wast."

This almost certainly indicates the origin of the Meer.

II. Barr-master or deputy to walk the field once a week, and to forfeit any mine not worked for 28 days, 10 days' notice to be given.

D. Mines to be forfeit after three weeks neglect.

III. All ore got, to be smelted at the lord's mill, but two smelters to be employed, one for the lord and one for the miners. All ore carried elsewhere to be forfeited.

M. Miners were free to smelt ore at any mill, but to pay one-tenth to the lord for the privilege.

IV. A miner may lawfully sell his mine with the Barr-master's permission, paying 1/- for the entry in the master's books.

M. Miner free to sell the hearth, etc., provided the ' lot ' of one-tenth be duely paid.

V. No ore or lead, etc., may be sold with an intent to evade the payment of the royalty or ' lot.'

VI. Barr-master to keep the lawful weights according to ancient standard, and may not alter any of them, without consent of the Steward and the majority of the grand jury. The weights to be used by miners and merchants alike.

D. " Miners and merchants shall have weights for their lead and measures for their ore." These were standard weights, etc., as in the case of the well-known standard Dish of Wirksworth.

VII. The lord to take every fifth piece of lead at the mill as his ' lot ' or royalty, without any deduction of charges.

D. The ' lot ' to be every thirteenth dish.

M. The ' lot ' to be every tenth dish.

VIII. Miners in return for lot, to have wood in the Lord's woods for all needs in their mine and for smelting their ore. The wood to be apportioned by the Barr-master.

D. Miners allowed wood and water for their lot.

M. Miners allowed wood.

IX. Theft of tools by miner punished by forfeit of 6/8 to the lord, and value of tools to him he hath wronged.

D. Forfeit of 5/4d. for first offence, 10/8d. for second, and banished from the mine for further offence.

M. Forfeit 6/8d. if tools of less value than 12d., but if of more value, then the miner to be put in his hut with all his tools, etc., " and there Set Fire about him, and burn his working Tools about him, and so from thenceforth be banished from ye Occupation for ever, before ye Face of all ye Miners there, and if ever he offend after, to be Committed to ye Law of ye Realm."

X. Miner absenting himself from work for one month, to forfeit to his partners double the charges they have been at, and 6/8d. to the lord.
M. Slothful workmen to forfeit their mine and be expelled the field.

XI. Theft of lead ore from any ground, punished by forfeit of ten shillings to the lord.
D. See under IX. where punishment applied to theft of ore as well as tools.
M. Thief to be banished from the occupation.

XII. A fine of 40/- to be imposed on a miner allowing his work or other persons' work to water up by his neglect.

XIII. A miner taking timbering from over any work, " whereby any Persons Goods may be lost, he shall forfeit to the lord 40/-, and pay the value of the Goods lost to the Owner thereof."

XIV. "If any Person shall conceal any Thing within the Ground, to the Hinderence of the next Taker, shall forfeit to the Lord or Farmer thirty-nine shillings, and lose his Mines."

XV. A person hindering his neighbour from going into his Works, the Barr-master and two of the jury may enter; if any miner hinder them, he shall forfeit 39/- to the lord.
M. Miner to be banished from occupation.

XVI. A miner to pay £5 per yard for underground theft by working into another man's ground, and 10/- per yard to the lord.

XVII. A fine of 6/8d. to be levied for neglect of dams and waterways for washing, or for interference with those of a neighbour.

XVIII. Wastes to be washed on the moor or at the mill, only when the miners and smelters are working on pain of 6/8d. fine to the lord.

XIX. Barr-master has right of search in case of any theft of ore at the smelt mill, and to levy a fine of 21/- against anyone hindering the search.

XX. Miners to have right to work up all wastes at the mill, but shall work them up within twelve months under pain of their forfeit to the lord.

XXI. Barr-master or Deputy to collect all fines for the use of the lord or Farmer.

XXII. Claim to any meer or vein must be made by arrest and by appeal to the Barr-master's court next following. If a verdict is given against the defendant then he must pay to the plaintiff all the ore won from the time of the arrest to the time of the verdict.

XXIII. A Barmoot Court must be called within ten days of an arrest.

XXIV. " That upon any Arrest made, the Pawnes, to wit thirty shillings shall be put in on both parts, into the Barr-master or his Deputies' Hands, at the Time of the Arrest, or within three Days next following, and in Point of Title for every Meer a Pawne."

XXV. Defendant to be allowed six days before the trial to prepare his defence.

XXVI. Barr-master or Steward ought Yearly to keep two Great Barmoot Courts on the Mines, one about after Easter, and the other about Michaelmas, if there be occasion, or within fourteen days before or after the said times.
D. and M. The same.

XXVII. All ore got between an arrest and trial, to go with the verdict. (This is implied in XXII.).

XXVIII. " We say, that honest and able Men ought to be summoned for Jurors, out of every Division within the said Liberty, and to be summoned as near the Court Day as may be, and of every Division some to serve, unless some just cause be shown to the contrary."
M. Similar, with fines for non-attendance.

XXIX. " We say, that able and fit Men (if they be not miners) if they have Parts and be Maintainers of Mines, and known by the Barr-master or his Deputy, to understand well the Custom of the Mine, they ought to serve for Jurors, especially in difficult and weighty Matters and Causes."

XXX. One verdict shall suffice for a question of wages, but two verdicts required to establish a title.

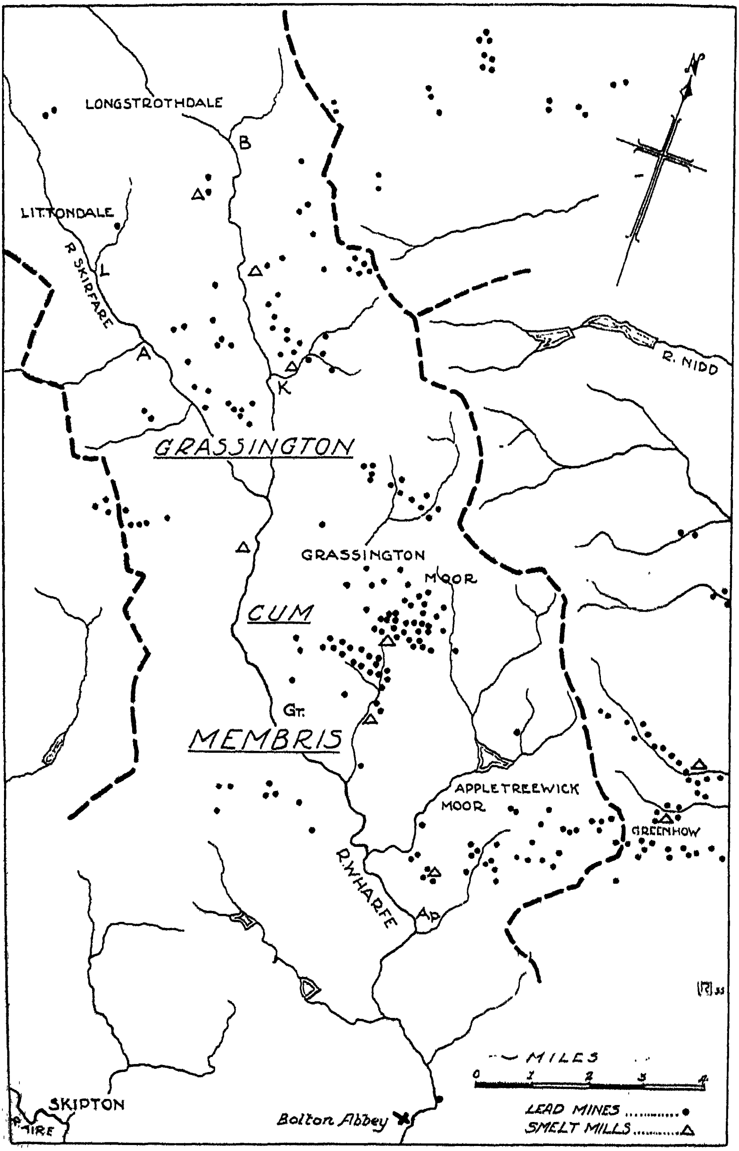
XXXI. Appeal is allowed within 14 days, for a second trial. Four or more of the Grand Jury may be asked to inspect the work in question and give their findings in writing, and they may allow further time " for workmanship to discover the Truth."

XXXII. No person ought to sue for matters relating to mining except in the Barmoot Court, and if they do, then should forfeit all the matter in dispute, and lose right to Plead in the Barmoot Court.

XXXIII. At a vein crossing, he who first comes to it shall work the cross vein to the extent of his quarter cord (allowed width of the meer).

It is seen from the above outline of the Laws, that particularly among the earlier ones, I. to XI., there is a great deal in common between these and the Laws of the Derbyshire and Mendip mines, while the later laws are largely concerned with fines for work or offences detrimental to the rights of the Royalty owner, and with regulation of the procedure of the Bar-moot Court. The earliest set of such laws, is that of Derbyshire, preserved in the bundle of the Exchequer and the Inquisition of the year of the Reign of King Edward I. 16 (1288). These laws remained in manuscript until they were printed in the "Complete Miner," London, 1688, and reprinted at various dates afterwards. The Mendip laws are preserved in more than one form. The earliest occur on a map of the Mendip mines, of about 1460, and others of slightly later date were preserved at the various mining offices of the Royalties, and added to at subsequent Courts, the laws of Chewton Manor extending from 1555 to 1773 by which time the original ten laws had been added to and extended to a hundred and five. The Grassington group have their greatest parallel in the earlier groups of laws both at Mendip and in Derbyshire, and seem to have been modelled on these. The date of the Grassington Laws must be a matter for surmise, but several factors suggest that the early part of the seventeenth century would be a likely time.

The monks of Bolton Abbey had worked lead mines in Appletreewick, purchasing them from James de Eston in 1300, and several items in their cartulary and accounts refer to them between 1300 and 1311. In 1464, Sir William Stanley obtained the grant of "all Mines of Cole and Leede," etc., belonging to the late Lord Clyfford. A few years later the attainder was reversed, and the Honour of Skipton reverted to the Cliffords. At the dissolution of the monasteries, much of the land of Bolton Abbey had passed


LONGSTROTHDALE
B
LITTONDALE
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GRASSINGTON
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GRASSINGTON
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MEMBRIS
APPLETREEWICK
MOOR
GREENHOW
R. WHARFE
Ap.
SKIPTON
R. AIRE
Bolton Abbey
MILES
0
1
2
3
4
LEAD MINES .... ●
SMELT MILLS .... △

Fig. 1.

to the Earl of Cumberland, while the manor of Grassington later came by will to the third Earl of Cumberland, and later by marriage with the Cliffords, the Percy Fee or Honour of Skipton came to the Dukes of Devonshire, thus uniting the Bolton Abbey and Clifford estates. By the beginning of the seventeenth century, most of the mineral ground of Wharfedale and of the Connonley district of Airedale, was in the hands of the Earls of Burlington, Lords Clifford, of whom the Duke of Devonshire is present representative.

During the reign of James I., the Earl of Cumberland introduced miners from Derbyshire into the Grassington district, and a rapid expansion of mining took place. Within the next forty years, mines were working in all parts of upper Wharfedale and in Littondale (the valley of the Wharfe's tributary, the Skirfare), and in Lothersdale, on Connonley Moor. It is not too much to suppose that the miners coming from Derbyshire brought with them their traditional laws, which were adopted and spread over the mining field. In 1737, we are told they had been in use time out of mind, and this might well apply to a little over a century. The extent of Grassington cum Membris may be taken as the extent of the Burlington lands in Wharfedale, i.e. from Bolton to part of Kettlewell, Longstrothdale, part of Littondale, and the Connonley field in Airedale, so far as lead mining was carried on. This area, with the exception of Connonley is shown on the map, fig. 1, on which the thick broken line encloses the area over which the laws of the " Rara Avis in Terris " would apply. The full extent and detail of their application can only be known when the Barr-master's books have been traced and studied, a work only as yet in its early stages.

REFERENCE.

*Raistrick, A. Lead Mining and Smelting in W. Yorks. Trans. Newcomen Soc. Vol. VII. 1927.

Raistrick, A. Yorks. Arch. Journ. Vol. XXX. 1930 for bibliography etc. of these pigs.

EXCAVATIONS AT SEWELL'S CAVE, SETTLE, W. YORKSHIRE.

A. RAISTRICK, Ph.D., M.Sc., F.G.S.

The cave described in this paper, is situated in the face of Common Scars, about 3 miles north west of Settle, alongside the main Settle to Ingleton road. The scars at this point are not very high, but have a footing of nearly 100ft. of scree and talus, partly overgrown with thin woods and scrub. The cave was discovered in 1932 by Mr. A. A. Sewell, as a very insignificant crevice at the foot of the scar, only to be entered with greatest difficulty on removal of some of the larger loose stones. The extremely restricted continuation of the crevice was seen to be floored by talus and cave earth, and a few fragmentary remains of bones, and a piece of Romano-British bronze work were all that indicated the presence of occupation debris. In the succeeding two years, a group of local workers, Messrs. T. Lord, T. L. Frankland, R. & T. Breaks, A. Simpson, and A. A. Sewell, members of a local archaeological society (called the Pig Yard Club, from the location of its meeting place in the older part of Settle Green) undertook the systematic exploration of the site in consultation with myself and Mr. Peach. We have kept in constant touch with the work, visiting the site and recording all finds as they turned up. Detailed plans have been kept of the work, but they are too large for publication here.

The greatest part of the labour has been expended in removing the enormous masses of falling rock debris that completely obscured the front of the cave, and that in many places had fallen upon and sealed in parts of the cave earths. In this work, some thousands of tons of material was handled, frequently single blocks of several tons demanding some days labour each. With the clearance of the debris it soon became clear that the site is really a rock shelter rather than a cave, the cleaned up site being a chamber about 40ft. long, 13ft. back to front, and about 10ft. high, measuring along the front of the scar. The floor of the shelter is partly occupied by glacial clay debris, on which rested a clay soil with rock debris, and abundant animal bones. The animal remains of the cave will be described in a separate paper, but it may be said here that they were scattered through all layers of the cave earth but the faunas of different layers agree closely with those of other caves in the area. The only outstanding feature of the fauna is the occurrence of several specimens of lynx, among the lower earths. The stratification of the deposits was well preserved in places, but in the main part of the cave there had been some disturbance by badgers (whose remains both recent and ancient are fairly abundant) and by rabbits, though fortunately not enough to confuse the

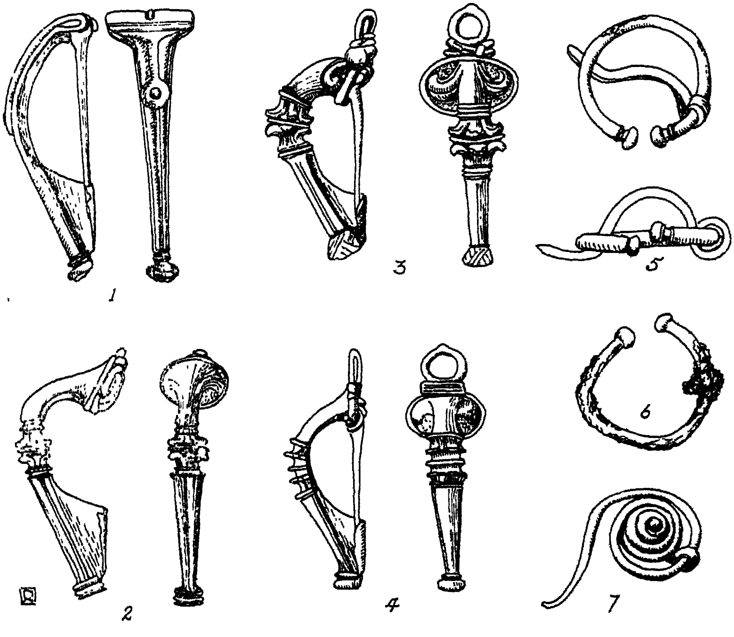


Fig. 1.

succession. The main work of these animals had resulted in some of the fragments of pottery etc. being brought out into the talus in front of the cave, but so far as careful search and examination could ensure, all these were recovered.

The occupations of the cave are confined to two main levels, though the irregularities of the cave floor, and presence of some enormous fallen blocks of limestone, prevented these "levels" being entirely horizontal. The digging was carried out throughout by means of shallow spits taken off narrow benches, all finds being referred to a datum level inscribed on the scar face and carried round the walls of the cave, and to two datum lines for horizontal position. The upper level was fairly rich in fragments of pottery, mostly of recognisable Roman types, with many objects of bone and bronze of Romano-British types. In one place, mingled with these were a few fragments of mediaeval pottery, in an area of disturbed ground. The lower level contained many animal bones, a few shards of pottery, fragments of flint and some human remains. There is some evidence that the human remains are parts of burials in the floor of the cave during occupation, as they are associated with considerable disturbance of the cave earth, but the stratification was not clear enough to prove absolutely the date of this. So far as the evidence goes, however it suggests a pre-Romano-British date for the burials.

The main results of the work can be summarised in a few words, the evidence being given in the descriptions of the remains, forming the bulk of this account.

The lowest human occupation layer was a thin earth resting on talus directly on the boulder clay. In this layer three fragments of worked flint occur, comparable in every way with the latest of the mesolithic flints so abundant on the Pennines, or with the early Neolithic. One flint is a partly finished leaf shaped point, but very small. Two pottery fragments are part of the rims of two Peterborough bowls, well preserved with deeply impressed ornament, and in the same place three frag-

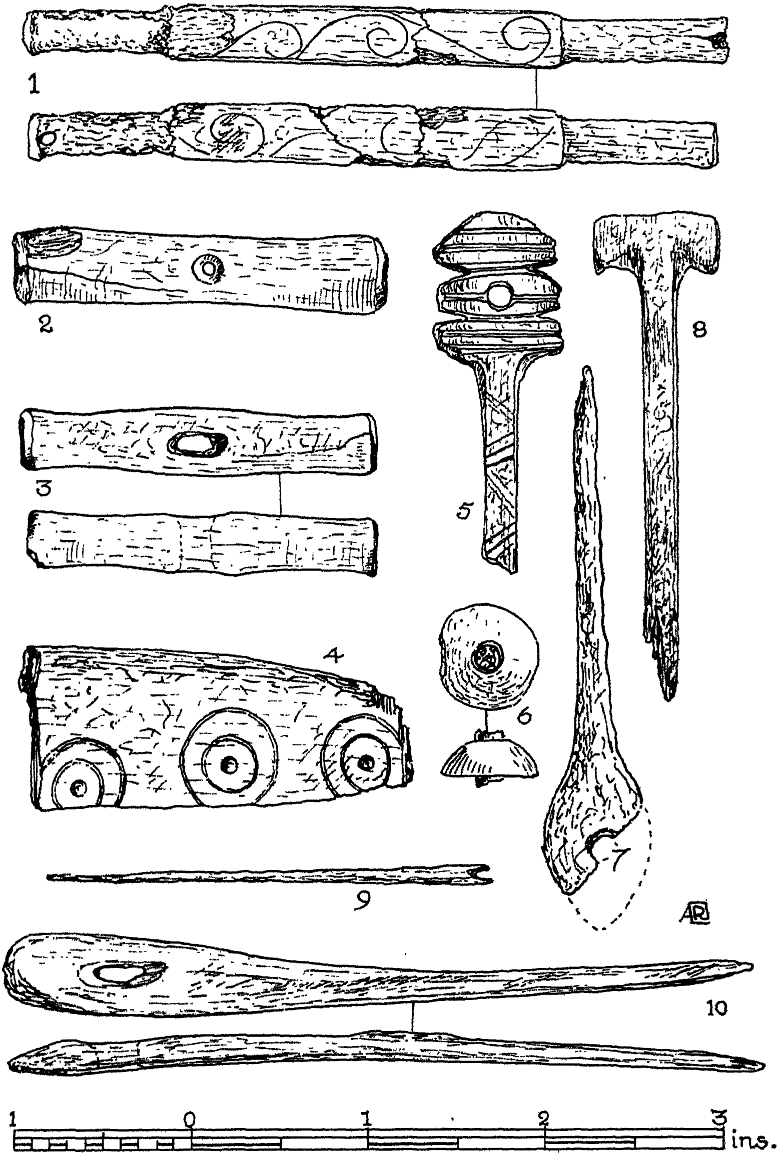


Fig. 2.

ments of bronze-age pottery. Several other small fragments of pottery identical in texture, thickness etc., with the bronze-age pottery, were got from other parts of the same layer, along with a few more fragments of similar colour and texture to the Peterborough ware. It is clear that in this first occupation we have the contemporary use or manufacture of beaker ware and Peterborough ware, along with survival flints of neolithic or earlier pattern. This picture agrees entirely with the telescoping of neolithic and bronze ages on the Pennines, that has been commented on before. Mr. H. Peake suggests that there is no real improbability of the Peterborough ware being made by Peterborough women captured by the earliest bronze-age invaders who penetrated to this area, and may have lived partly by plunder, partly by hunting. Peterborough ware has also been found at two other sites in the locality. V. G. Childe (Prehist. Scotland 1935) has recently suggested that the overlap of Peterborough and Beaker ware in the west of England and in Scotland may support the provisional view that this ware may be regarded rather as an incident of the Beaker invasion than as evidence of a distinct period. With this the evidence of the cave is in entire accord.

The later occupation has provided a rich group of Romano-British objects similar in many respects to those furnished by other caves in the area. The main features of this assemblage are the bronze brooches of harp and penannular forms, carved bones including the puzzling bone "spoons" with perforated bowl, bone combs, and needles, and a number of iron knives and swords. Stone spindle whorls and hones are present, and numerous fragments of bronze plate. The pottery and bronzes agree in indicating an occupation about the middle of the second century A.D. most of the material being dateable about the second quarter of the century. There is one coin of middle third century, the only trace of the later occupation that so many other of the caves show. In addition to these remains are a few fragments of mediaeval pottery, all of the 14th or 15th century. This again can be matched in both Dowkerbottom and Elbolton caves.

The very fragmentary state of the Romano-British remains and its type, agree with all the other local caves

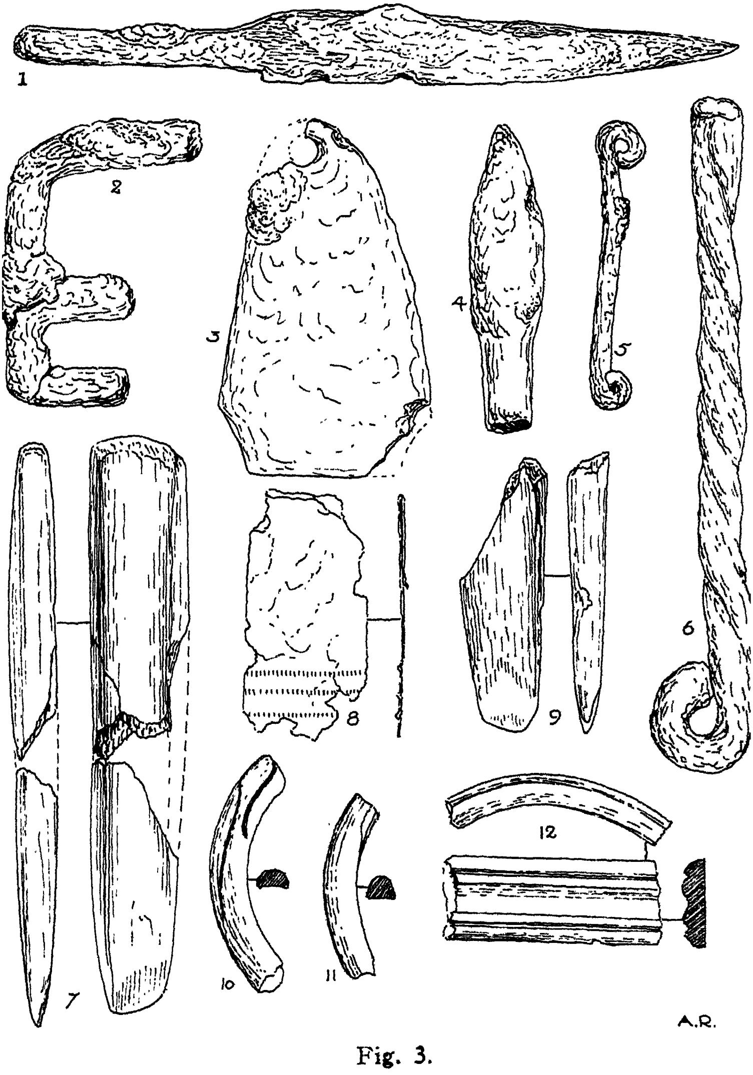


Fig. 3.

in suggesting a temporary occupation by refugee population, during the second century, with the addition in this cave of parts of a soldier's accoutrements, in the swords, javelin head, and (?) mail plates. These may of course have been plunder during the rebellion.

DESCRIPTION OF REMAINS

Bronzes. Fig. 1. 1 to 7.

Fig. 1.1. Head-stud brooch, type Q (Collingwood, Arch. Roman Britain, 1930). Brooch cast as flat tapering strip, head formed by piece bent back and secured by rivet at mid-bow. Foot is seal shaped, pin hinged, head loop missing. An early type, A.D. 100-130 Romano-Brit., north of England.

Fig. 1.2. Trumpet brooch, type R (ii), (Collingwood). Trumpet form head derived from pre-Roman type (Aylesford type). Central part of bow is a cushion or disc embraced by two members each consisting of an acanthus. Foot circular with three moulds, lower part of stem triangular section, rising to low ridge down centre. Head loop and pin are missing, spring for pin present. A.D. 100-150 north of England. Traces of the workshops where these were made are found at Brough-under-Stainmoor and Kirkby Thore. (Collingwood, *op. cit.*). This is the best-known type of Romano-British brooch, *cf.* Elslack, Attermire, etc.

Fig. 1.3. Trumpet brooch similar to 2 but more ornate. Trumpet head is moulded with conventional eyes and nostrils of animal head. Foot is a moulded conical cushion, with a pattern of diagonal lines. Head loop is present and is a massive casting, moulded on wire original. Pin present and hinged, not sprung. Type R (ii), A.D. 100-150.

Fig. 1.4. Trumpet brooch, acanthus elements very much conventionalized and very thin, appearing in side view almost as thin plates. Head loop and pin hinge in a single piece of wire. Head plate with one band of fine ornament. Foot as in 2, pin hinged and not sprung. Type R (ii).

Fig. 1.5 and 6. Penannular brooches. A type common throughout the Roman period in Britain. Writhen knobs. A type present in all the west Yorkshire caves.

Fig. 1.7. Half of a double spiral brooch. One spiral and part of pin and pin loop, present.

A plain, heavy bronze ring, and six fragments of bronze plate (Fig. 3.8) possibly represent harness trappings. Half of a third penannular brooch with well-preserved knob. (Fig. 4.14)

Coin. A bronze denarius of Galienus (A.D. 253-258).

Bone. Fig. 2.1. Squared bone rod, with round shank ends, rather like an axle-tree but small; 4 inches long and ⅝ inch wide, with incised flowing scroll pattern on each flat side. The extreme ends

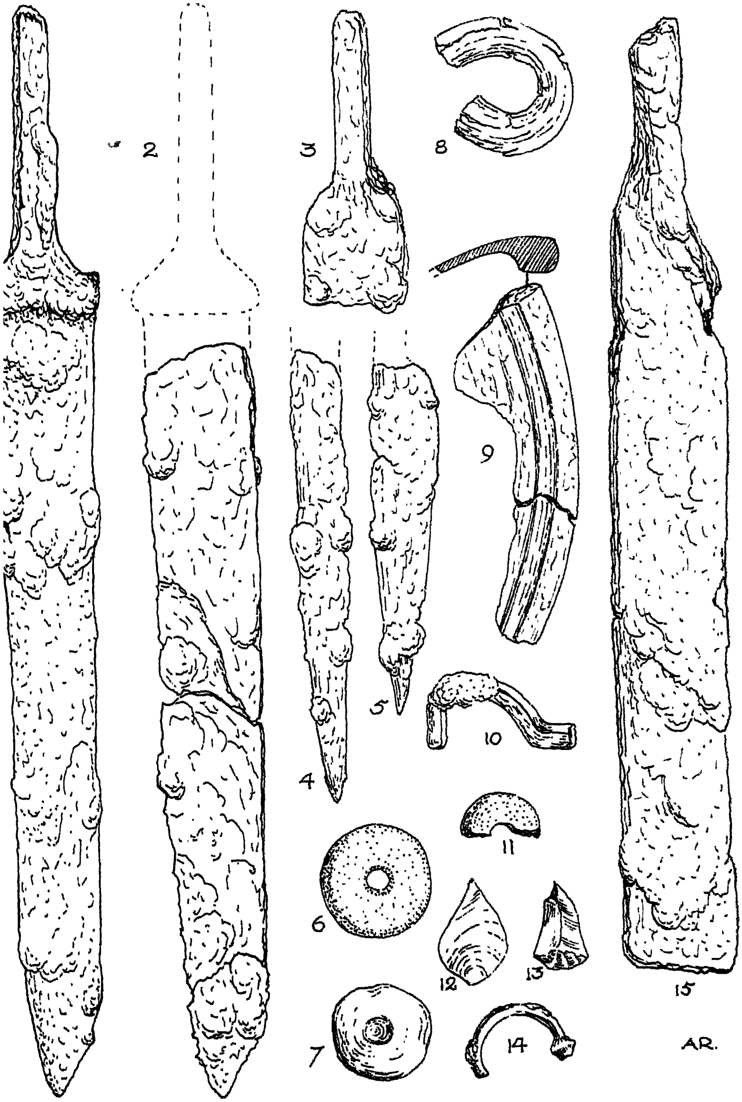


Fig. 4.

are pierced at right angles to the axis and at right angles to each other. Nothing like it is known from any other of the caves, and its use cannot be suggested.

Fig. 2.2 and 3. Bone toggles of a type common in the local caves. One of the examples, 2, is drilled along the axis by a fine hole, and its central hole is round, not oval as is usual.

Fig. 2.4. Part of the back of a bone comb, ornamented with concentric circle pattern. This pattern is common in the local caves, *cf.* large toggles from Dowkerbottom (Craven Mus.), etc.

Fig. 2.5. Stem of bone spoon, with expanded head, ornamented with deeply incised grooves, and perforated. A similar but complete example was obtained in Attermire cave.

Fig. 2.6. Head of bone pin with part of pin shank in place.

Fig. 2.7. Part of stem and the perforated bowl of a spoon.

Fig. 2.8. Stem and plain head of bone spoon.

Fig. 2.9. Fine needle of bone, broken across the eye.

Fig. 2.10. Large bone needle, common type in the Pennines.

Fig. 3.7 and 9. Very fine chisel or gouge made from part of cannon bone of ox. The whole area of the chisel has been ground and very well shaped. The edge is carefully ground from both sides.
Bone point made from the tip of a horn, presumably red deer. Sharpened and shaped by grinding.

Stone. Fig. 4.6.7.11. Spindle whorls of stone; 6, fine-grained sandstone; 7, not finished, made of fine grit; 11, sandstone.

Fig. 4.12.13. Flint points, with microlithic chipping of the edges.

Fig. 3.10.11. Portions of bracelets, of hard pottery or artificial stone ware, one decorated with lines of deep blue enamel.

Fig. 3.12. Part of a bracelet of lignite, ornamented with deep grooves and moulding on outer surface.

Iron. Fig. 3.1. Iron knife, 5¾ inches long, square tang 2 inches, and blade tapering evenly from ⅜ inch wide to a sharp point.

Fig. 4.4 and 5. Portions of two similar knife blades. This is a type found in most of the caves of this area, but is not usually so well preserved, owing to its fine blade rusting away.

Fig. 3.2. Ward end of a common Roman slide-lock key.

Fig. 3.3. Possibly the plate from the plate-mail covering of a soldier's jacket. Other fragments of similar plates have been found in this and other caves.

Fig. 3.4. Javelin point of typical Roman form, part of light, hand-thrown javelin.

Fig. 3.5. Short piece of iron wire with toggle ends, possibly a strap loop.

Fig. 3.6. Piece of wrought-iron bar, spirally twisted with forged loop at one end.

Fig. 4.1. Short sword or gladius, complete except for bone handle strips. This was carried by the legionary foot soldier of the early Empire. Began to go out of use in the second century, and so agrees in date with the rest of the finds. This would perhaps strengthen the determination of Fig. 3.3. as a piece of plate mail.

Fig. 4.2. Part of blade of a gladius, parallel or nearly parallel sided, blade 12 inches long.

Fig. 4.3. Haft end or tang of a large knife or dagger.

Fig. 4.10. Square iron-wire object, incomplete.

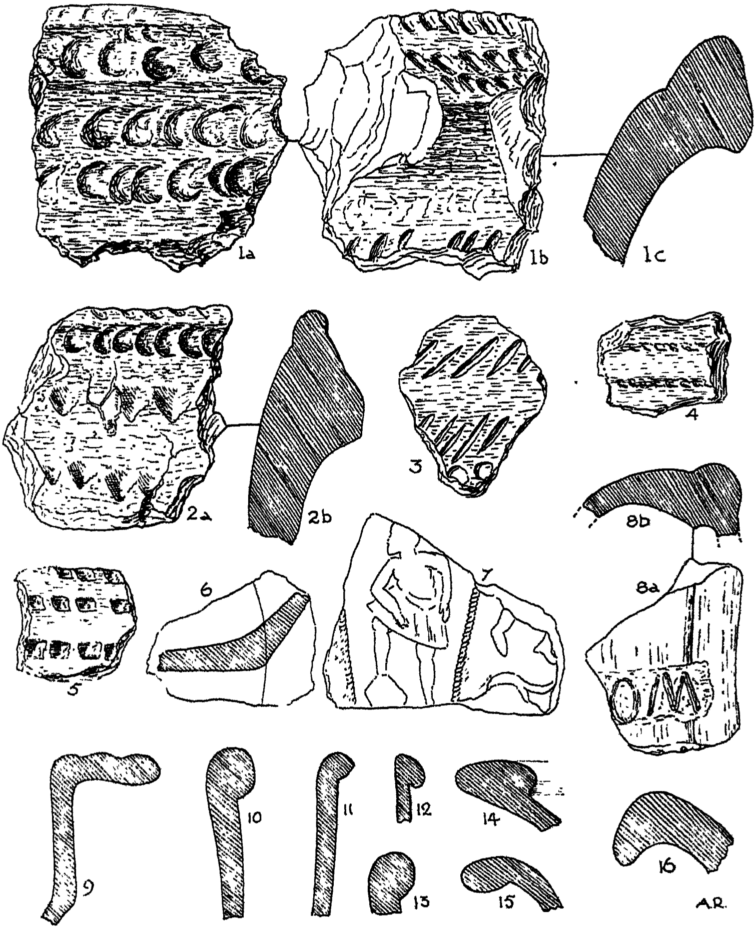


Fig. 5.

Fig. 4.15. Possibly unfinished blade blank for a gladius; has much in common with some of the "currency bars." (This is in the Settle Museum collections, and is included for comparison. It is from a local cave.)

Fig. 4.9. Fragments of the rim of a cooking-pot or bucket.

Lead. Fig. 4.8. Heavy ring of lead, 2 inches outside diameter, of circular section, ½ inch diameter. Ring not closed.

In addition to all these articles described and figured, there are several fragments of bone and metal, not sufficiently complete or distinct to have separate mention.

Pottery. (Report by M. Kitson Clark, M.A., F.S.A.)

Bronze Age. Fig. 5.1 and 2. Coarse, blackish, hand-made paste with very large grit. Outbent bevelled rims, 1 of rectangular, 2 of triangular section. Ornamented both rim and inside rim with bird-bone impressions of different sizes. 2 has further decoration by slight impress of inclined square stick, on body. Peterborough bowl. *Cf.* Arch. LXXXVIII. Rims, Ant. III, 288. Pl. viii (duck) inside. Pl. v. blackbird, outside.

Fig. 5.3. Light red, hard with very light grit, ornamented with two lines of finger-nail impressions and one row of stabs; outer surface smooth. Bronze age.

Fig. 5.4. Beaker ware. ? B beaker. Fine, soft, light paste, no grit, ornamented with faint lines of impressed cord, "soapy," burnished surface. Several small, badly rubbed fragments of this ware.

Fig. 5.5. Very similar paste, outer surface a little less red, ornamented with three rows of stabs, stabbed with pointed implement, stabs running in reverse direction. Bronze age.

Roman. Great quantities of fragmentary pottery of Roman type were obtained, of which the following are the most distinctive rim fragments:

Fig. 5.6. Portion of base of a cook-pot; grey, gritty, sandy paste.

Fig. 5.7. Samian ware; part of the lower half of bowl 37; coarse ware with fairly dark glaze. Shows part of two panels divided by bead lines.

i. Man standing, chin on hand, almost identical with Wroxeter, 191, pl. xvi, 18. See also pp. 44 and 37 from a bowl of a mould of Cinnamus used by Mercator. Trajan-Hadrian Wroxeter deposited dated not later than mid 2nd century.

ii. Feet of another figure.

The shard shows a rivet hole, so the bowl has been mended.

Fig. 5.8. Rim of mortaria. O.P. pl. lxxiii. Curle Type 21. Stamped hard, creamy paste; groove under the rim; hooked hammer head type. *Cf.* Wroxeter 1912, p. 77, fig. 19. 1st-2nd century. Fragments of several other mortaria are present, but this is the only stamped piece.

Fig. 5.9. Reeded rim of carinate bowl with two grooves. 1st or early 2nd century; light red paste. Cf. Malton fig. 1.9 from rampart.

Fig. 5.10 and 13. Rims of two separate dishes of 15/31 both about 10 inches diam.; one coarse dark, one coarse orange glaze. Fragments of similar paste and thickness very common, with numerous small fragments of similar rims.

Fig. 5. 11 and 12. Rims of two finer, smaller dishes of 18/31. Imita tion fine hardware, but hardly any glaze. Again, other fragments of this ware are very numerous.

Fig. 5.14. Light, fine, calcite, gritted ware, brownish-black paste with white grits (probably shell fragments). Lincolnshire type, 3rd-4th century.

Fig. 5.15. One of many fragments of light grey paste, outbent rim of cook-pot. Almost the commonest pottery on the site.

Fig. 5.16. One of very many fragments of mortaria rim, of soft ware. Many fragments are heavily gritted on the inside. In addition to the figured material, over 50 fragments of pot were obtained, of pastes and textures similar to some of those described.

HUMAN REMAINS

(Report by Sir A. Keith, F.R.S.)

There are six, perhaps more, individuals represented among the fragmentary human remains. Two are young children; the rest are adults, none of them of very great age.

Individual 1. A man. We (my assistants and I) have succeeded in fitting about a dozen fragments together to form a considerable part of the vault of his skull. We also have the right and left ascending rami of his lower jaw and half (the right half) of his upper jaw. No fragments of limb bones have been found. The state of the bones do not suggest a great antiquity. They are not heavily mineralized and black soil still clings to their surfaces and fills their porasites. We suggest they may be late celtic (pre Roman).

This man was over 40 years of age and had a thickish skull the frontal bone, in its upper or coronal part measuring 8 mm. in thickness. The vault, so far as it has been reconstructed, suggests a narrow and long skull or head.

The rami of the lower jaws are very peculiar, their peculiarities being due to the strength of the muscles of mastication attached to them. The lower angles of the rami (which causes the prominence of the jowls) are strongly averted and therefore prominent in the cheek. The coronoid processes are also bent outwards. Thus the outer aspect of the rami is hollow or concave, especially in a vertical direction. Further evidence of the strength of the muscles of mastication is found in the width of the ascending ramus, which measuring at its narrowest part 39 mm., 4 or 5 mm. more than is usual in jaws of pre-roman Britons. The teeth are moderately worn. The nose was narrow, about 22 to 23 mm. in width. All these characters are in keeping with the supposition that we are dealing with the remains of a celtic speaking British people.

Individual 2. A child of about 3 years represented by fragments of lower and upper jaws. The dentition shows it to have been about 3 years of age.

Individual 3. A child of about 2½ years represented by fragments of the upper jaw.

Individual 4. An adult probably a woman represented by part of a lower jaw, some teeth and possibly some fragments of skull.

Individual 5. Probably aged, represented by porous fragments of a very thick skull.

Individual 6. Represented by skull and fragments. These may belong to more than one individual.

There are also fragments of a young pig's skull. Its state of mineralization is much the same as that of the human fragments. Why have the bones become so broken? Why are all traces of limb bones absent? How did the bones come into the cave?

The explanation I offer is that the cave was used as a burial place that when new burials were made the older interments were disturbed. The cave may have been inhabited after the original burials were made. The inhabitants may have dug in the floor and thrown away such bones as came to be exposed. The jaws and skull are more durable than the limb bones. The bones may have been disturbed by burrowing animals. I did not notice marks of gnawing on them.

Conclusion.

The main features of the two occupations of the cave have already been detailed, and it only remains to add a note of the relation of this cave to the others in the same area of the Pennines. All the local caves have one feature in common, a comparatively short occupation during the second century A.D., yielding an assemblage of Romano-British objects, remarkably incomplete and fragmentary. All include the bone needles, and many bone objects that appear as crude makeshift when compared with the rich bronze brooches and (in some caves) enamels. Coins are remarkably scarce. The whole assemblage rather suggests a temporary refugee population, carrying with them the richer ornaments of dress, a few pots, used till they disintegrate, and making abundant use of bone, as toggles, needles, tools, etc., along with a small amount of iron, mainly knives and weapons. The whole group of caves in Craven is pressing home more and more the picture first outlined by Richmond (Y.A.J. XXVII, 211ff) for the opening years of the fourth century, when "the wild hill-men who lived about Ilkley and Skipton broke out into sudden and alarming revolt." Under such circumstances, culminating in the destruction by fire of both forts and villas, we can understand Romano-British families seeking refuge in the caves of Craven. This occupation is common to all the larger caves, and is marked by abundance of late third century pottery and coins. Fragments of this are represented in Sewell's cave. The main occupation of this and all the other caves, however suggests very strongly and forcibly an exactly similar rising about the middle of the second century. It is at this date that all the lead mining activity ceases, and that a gap appears in all the Pennine Roman remains (Raistrick, Y.A.J. XXXI, 214ff).—Indeed, the mid-Pennine area of Craven, remained throughout Roman times, a difficult, hilly country, traversed by few main roads, and only bordered by important stations and forts. It seems probable that at least two periods of riot and insurrection were experienced in the middle of the second and beginning of the fourth centuries.

The material obtained by this excavation is at present in the museum of the excavating society, but will eventually be lodged in one of the public collections.

SOMATIC CHROMOSOMES IN URTICA.

by

PHILIP G. FOTHERGILL.

Introduction.

Very few chromosome numbers are known in *Urtica.* Strasburger (1910) and Meurman (1925) have given different numbers for *Urtica dioica,* while Heitz (1927) has supplied figures for *U. pilulifera, U. Dodartii,* and *U. biloba.* Earlier he obtained a variable count for *U. dioica.* Tischler (1931) quotes Krause as giving a number for *U. pilulifera.* The chromosome morphology on a comparative basis has not been studied by anyone. An examination of root tip material of *U. Dodartii* showed that the number of chromosomes present was not the same as that given by Heitz, and also indicated that further study would be profitable. This led to an investigation of eleven species and varieties of *Urtica.*

The size relationships and the obvious aspects of the chromosome morphology have been investigated. While the number of species and varieties dealt with is too low to give anything but a preliminary idea of the relationships of the various species in the genus, some interesting information has been obtained. It is hoped to be able to continue investigations into other species at a later date.

Method of Preparation.

Root tip material only was used, and was generally obtained from fully grown plants as they gave the best results. With two exceptions (*U. dioica* and *U. urens*) all the plants were grown from seed obtained from botanical gardens in Europe. Local wild plants of *U. dioica* and *U. urens* were transplanted to pots where they gave an abundance of new root tips.

The root tips were fixed in Langlet's modification of Nawaschin's fluid. Sections were cut at a thickness of 8μ and stained in Heidenhain's iron-alum hæmatoxylin. This fixative and stain was found to be generally satisfactory and no others were tried. Due to the amount of tannin, or tannin-like substances, in the cytoplasm it stained almost equally with the chromatin. This difficulty, however, was overcome by shortening the period in the mordant and lengthening the time in the stain. Usually the sections were mordanted for one hour and stained for twenty-four hours. With this treatment it was found possible to get the metaphase chromosomes to stand out clearly against an only slightly greyish background of cytoplasm. The same difficulty was encountered by Wilkinson (1934) in various species of *Salix*. He overcame it by staining for several days.

All the plates shown in the illustrations were drawn using a Leitz $\frac{1}{12}$ in. oil immersion objective and an Abbé camera lucida. The magnification in all cases is × 4050 reduced to 2700 in reproduction.

In order to obtain chromosomes of comparable sizes only plates from the cortex were drawn. Since, usually, all the chromosomes lie flat on the plate it was possible to get their lengths directly from the camera lucida drawings by using a very fine pair of surveyor's dividers, after the method described by Miss McCullagh (1934).

Chromosome Numbers.

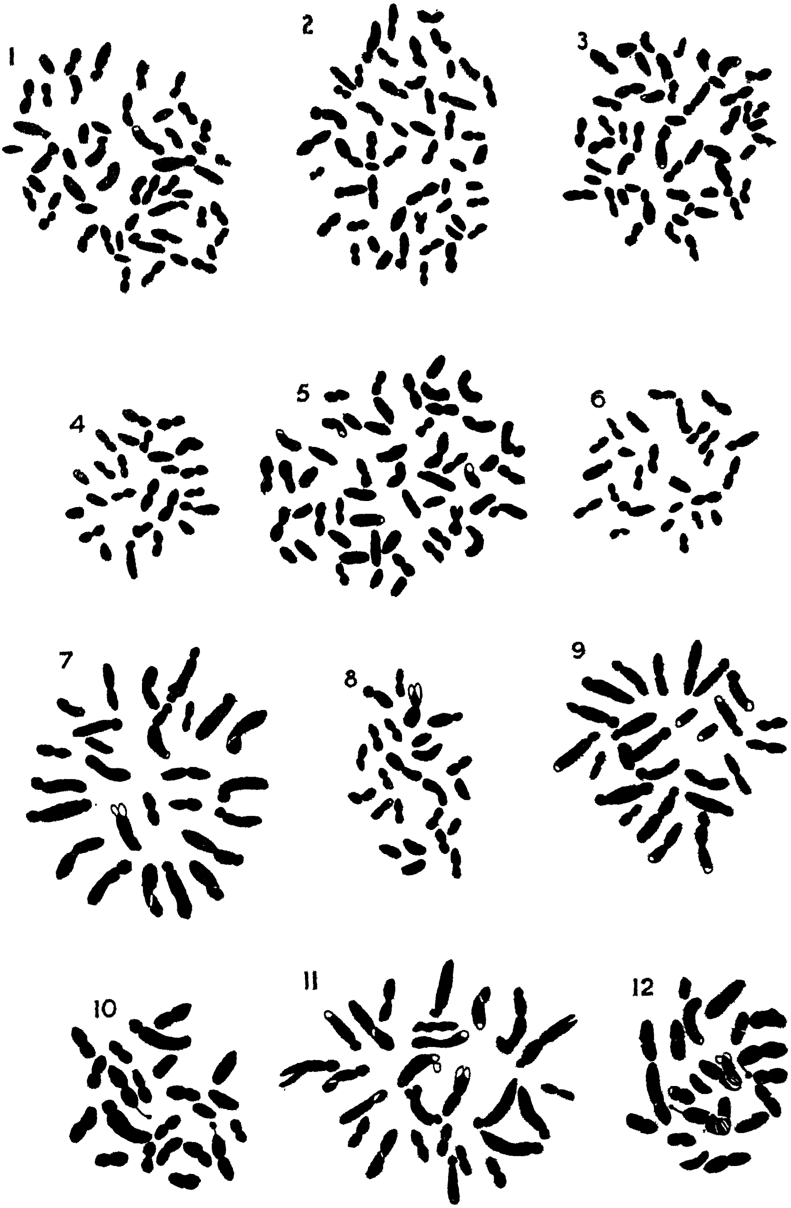
List of Species and Varieties Studied, with sources of material and Somatic Chromosome numbers. (Previous counts are recorded in brackets.)

Urtica urens L., local	$2n=24$	(Meurman $n=12$)
Urtica atrovirens Req., Toulouse	$2n=26$	
Urtica grandidentata Moris, Bucharest	$2n=26$	
Urtica pilulifera L., Liège	$2n=26$	(Heitz Krause $n=13$)
Urtica pilulifera s.v. *balearica*, Sicily	$2n=26$	
Urtica pilulifera var. *Dodartii* L., Esthonia	$2n=26$	(Heitz $2n=24$)
Urtica cannabina L., Lithuania	$2n=52$	
Urtica dioica L., local	$2n=52$	(Meurman $n=24$, Heitz $2n=48$-49)
Urtica kioviensis Bog., Lithuania =U. *dioica* var. *kioviensis*	$2n=52$	
Urtica dioica var. *angustifolia*, Bucharest sent as U. "*Nemorosa*"	$2n=52$	
Urtica gracilis Ait., Bucharest =*U. dioica*	$2n=26$	
Urtica membranacea Poir., Liège	$2n=22$	

Urtica grandidentata Moris is stated by Weddell (1856) in his Monograph on *Urticales* and by the Index Kewensis to be a synonym of *U. atrovirens* Req. The plants grown under these names proved to be identical morphologically and cytologically. Hence *U. grandidentata* will not need to be referred to further. The Index Kewensis also lists *U. Dodartii* L. as a definite variety of *U. pilulifera* L.; so also *U. balearica* L. is a sub-variety of *U. pilulifera*; *U. kioviensis* Bog. and *U. gracilis* Ait. are stated by Weddell to be varieties of *U. dioica* L. *U. nemorosa* H.B. and K, however, is not an *Urtica* but is variously given as *Fleurya æstuans* or *F. cordata*, species of another genus in the Tribe *Urereae*. The specimens of *U.* "*nemorosa*" worked with here, however, have opposite leaves, and this character immediately places it in the genus *Urtica* (*Fleurya* has alternate leaves). It was further identified as *U. dioica* L.; the nearest variety it could be run down to was *angustifolia*. In its young stage it resembles *U. gracilis* Ait., but as it grows it comes near to the common *U. dioica* L. In chromosome number it agrees with *U. dioica* and its variety *kioviensis*.

Some of the chromosome numbers given above differ from those given by previous workers. Thus Strasburger (1910) gave 36 as the somatic number for *U. dioica*, while Meurman (1925) came to the conclusion that the number was $n=24$ from admittedly doubtful diakinetic counts. He concluded this was the number because that of *U. urens* was undoubtedly $n=12$. Later Heitz (1926) stated the number to be $2n=48$-49. The number $2n=52$ is given in this paper for *U. dioica* and its varieties, except var. *procera*, which is $2n=26$. It must be acknowledged that the common *U. dioica* L. was difficult to count due to approximation of some of the chromosomes. The varieties, however, gave no difficulty.

The number $n=12$ for *U. urens*, given by Meurman (1925), is confirmed by the present somatic count of $2n=24$. Heitz (1927) gave $2n=24$ for *U. pilulifera* and *U. Dodartii*, but his figure of *U. pilulifera* showed twenty-five chromosomes. These two forms examined here both showed the



1. Urtica Kioviensis. 2. *U*. Dioica. 3. *U*. "Nemorosa."
4. *U*. Atrovirens. 5. *U*. Cannabina. 6. *U*. Gracilis.
7. *U*. Pilulifera. 8. *U*. Urens. 9. *U*. Balearica.
10. *U*. Membranacea. 11. *U*. Dodartii. 12. *U*. Membranacea.

number of chromosomes present to be undoubtedly 2n = 26. This number is also found in the variety *U. balearica* L.. Tischler (1931) states that Krause gives n = 13 for *U. pilulifera.*

The Somatic Chromosomes.

The metaphase chromosomes appear, as a rule, as straight rods; some of them are occasionally seen to be slightly curved or bent, but U-shaped or J-shaped chromosomes were not encountered. Both primary and secondary constrictions, the kinetic and akinetic constrictions of Delaunay (1929), are present in some of the chromosomes. In a few of the smaller chromosomes no constrictions at all are visible. In these cases then the spindle fibre attachment would seem to be terminal. Several workers, including S. Nawaschin (1916) and Taylor (1926) consider that the insertion of the spindle fibre is never truly terminal. Nawaschin considers that in cases where the attachment appears to be terminal there is always present a tiny particle which he calls "Fuhlerköpfchen." Delaunay (1929) states that all transitions from the short arm or knob, to this small granule exist. No such small particles, however, could be discerned in the small chromosomes of *Urtica.* McCullagh (1934) also failed to find any in those chromosomes of *Plantago* which apparently showed terminal fibre attachment.

Throughout the species examined there is a rather wide divergence in chromosome size. The smallest chromosomes measure 0·4μ and occur in *U. atrovirens*, *U. dioica* and its varieties. The smallest chromosome in *U. cannabina* measures 0·6μ, but the difference of this from the above is within the limit of drawing error. The longest pair of chromosomes occurred in a plate of *U. Dodartii.* Each of them measured 2·3μ. It seems, however, that in this plate the chromosomes are abnormally long—there is a 20 per cent. difference between the chromosomes in different plates of the same section. The more normal length, at the fully contracted metaphase stage, is probably that as found in the longest chromosomes, *U. pilulifera*, *U. balearica* and also in some plates of *U. Dodartii*, namely a length of 1·9μ.

The constancy of the relative sizes of the chromosomes enabled them to be placed in three size classes—large, medium or small, after the scheme of Delaunay (1926). This enables one to construct a formula for each species and variety leading to a better understanding of the relationships between the complements. In the formulæ given below the large chromosomes are denoted by A, the medium by B, and the small by C.

List of species and varieties with their length formulæ.

Urtica urens L.	2(3A, 4B, 5C).
Urtica atrovirens Req.	2(2A, 6B, 5C).
Urtica pilulifera L.	2(4A, 6B, 3C).
Urtica pilulifera s.v. *balearica* L.	2(4A, 6B, 3C).
Urtica pilulifera var. *Dodartii* L.	2(4A, 6B, 3C).
Urtica cannabina L.	4(2A, 6B, 5C).
Urtica dioica L.	4(2A, 6B, 5C).
Urtica dioica var. *kioviensis* Bog.	4(2A, 6B, 5C).
Urtica dioica var. *angustifolia* (=U. " nemorosa ")	4(2A, 6B, 5C).
Urtica gracilis Ait. (=*U. dioica* var. procera)	2(2A, 6B, 5C).
Urtica membranacea Poir.	2(A, 8B, 2C).

As regards morphology the chromosomes fall into distinct types. *Urtica atrovirens*, *cannabina*, *dioica* and its varities, including *U. gracilis*, obviously possess a similar set of chromosomes. The chromosomes of these species are small—the smallest measures 0·4μ and the longest 1·3μ—but still each complement can easily be divided into three size classes. The common haploid formula for each of these species is then 2A, 6B, 5C. It seems likely that all of the median and large chromosomes are constricted. The constriction is usually median, but from 2-4 of the larger chromosomes in the 26-chromosomed species have each a sub-terminal constriction, while the 52-chromosomed species show from 4-8 of these chromosomes. This, in conjunction with the chromosome number and the common basic chromosome formula, is evidence of polyploidy. The 26-chromosomed species could then be taken as diploids with a base number 13, while the forms with 52 chromosomes would be tetraploids.

Some of the smallest chromosomes are medianly constricted, but in others no constriction is discernible. *U. atrovirens* differs from *U. gracilis* in the possession of only two sub-terminally constricted chromosomes to the latter's four. All the above species except *U. atrovirens* are placed in the same sub-section in both Weddell's and Engler's classifications.

Urtica urens possesses chromosomes of a similar type to the above, but differs from them in number. Specifically it resembles *U. atrovirens* in possessing a pair of large medianly constricted chromosomes and a pair of large sub-terminally constricted ones. It also possesses the same number of C type chromosomes. Weddell places these two species in two related sub-sections in his classification. The difference in chromosome number supports this; Engler, however, places them in the same group. Their close relationship is indicated by the similar morphology of their chromosomes. Thus *U. atrovirens* could have arisen from *U. urens* by addition of two chromosomes. The basic number of these species would then be 12. The reverse might also have taken place.

The chromosome sets of *Urtica pilulifera* and its varieties present a totally different appearance from those of the rest of the species examined. Six small type medianly constricted chromosomes are common to all the species except *U. membranacea*, but the majority of the chromosomes of *U. pilulifera* and its varieties are much larger than the largest of *U. cannabina* or *U. dioica*. The largest is about 2·3μ. Thus the chromosome formula (4A, 6B, 3C) for *U. pilulifera* and its varieties is different from the others. All, except perhaps two small chromosomes, are constricted. The constrictions are median in the medium-sized chromosomes and sub-terminal in the larger ones. Four of the larger chromosomes also seem to possess secondary constrictions. One pair of these has a sub-median primary constriction and a sub-terminal secondary constriction. The other pair are dumb-bell shaped with two sub-terminal constrictions resembling a chromosome in *Muscari longipes* as shown by Delaunay (1926).

U. pilulifera and its varieties are placed by both Weddell and Engler into a single group, separate from the above species from which they differ so greatly.

U. membranacea remains to be considered. Its chromosome number separates it from the others at once, and indeed it is placed by both Weddell and Engler in a distinct sub-section. The chromosomes of this species seem to be much fatter in proportion to their length than those of any of the other species. Morphologically the similar types of chromosomes are found here as in the others. The majority are medianly constricted, some are not visibly constricted. *U. membranacea* is peculiar in the possession of one very long pair of chromosomes with a sub-terminal constriction. Each of the other large pair of chromosomes is medianly constricted and satellited. A slight but distinct size difference was occasionally noticed between these satellites. This may have little or no significance, but it is interesting to note that S. Nawaschin (1912) differentiates between two races of *Galtonia candicans* by a size difference in the satellites; while Taylor (1926) has also found small differences between corresponding satellites in a given cell and in different roots.

The constrictions in *Urtica* chromosomes appear in two forms—first as an apparent drawing-in of the chromatic material, and secondly as interruptions in the chromosome so that it appears as several parts of a single whole. This transverse slit or interruption is only very small, and seems to occur most frequently in chromosomes which have not reached the fully contracted stage. The transverse slits do not appear constantly, but when visible they always occupy the position of a constriction. In the prophase stages constrictions have commonly been described as definite interruptions in the chromatic threads. These usually disappear before metaphase is reached. Hance (1918) noticed this in *Oenothera scintillans* De Vries. Taylor (1926) recognised such constrictions as " light bands across an unconstricted shaft." Delaunay (1929) also gives figures of the same phenomenon, although the slit is almost broad enough to justify the separated body being called a large trabant, but for the absence of the "thread." Kaufmann (1934), working on *Drosophila melanogaster*, states that the somatic chromosomes under favourable conditions show both primary and secondary constrictions as "achromatic interruptions in a chromatic thread." He recognises two distinct types of constrictions —the "gap" type above and the ordinary type, which he calls an "indenture" represented by a reduction in the diameter of the chromatids. Kaufmann also considers that the second type arises from the first by normal contraction of the chromosomes during karyokinesis or during the technical processes involved in preparing the material. A plate showing an unusually large number of "gap" constrictions in *U. membranacea* is shown in fig. 12.

Classification and Discussion.

The classification of the genus *Urtica*, according to Weddell (1856), is given in an abbreviated form below. It is divided into two main sections and then further subdivided :

§1. Inflorescence androgynous
    A. Stipules free
        (*a*) Petiole short
            —*U. urens*.
        (*b*) Petiole long
            —*U. atrovirens*.
    B. Stipules united
§2. Inflorescence unisexual
    A. Stipules free
        (*a*) Inflorescence spherical
            —*U. pilulifera* and varieties.
        (*b*) Inflorescence a spike or panicle
            —*U. cannabina*, *U. dioica* and varieties.
    B. Stipules united, apices sometimes bifid
            —*U. membranacea*.

Engler's classification differs but slightly from this. He does not recognise the further subdivision of subsection A, section 1 whereby Weddell separates *U. urens* from *U. atrovirens*. While both these species show chromosomes of a similar type, the difference in chromosome number and formula rather points to Weddell's classification as more correct. *U. cannabina* and *U. dioica* and its varieties are placed by both systematists in the same group. The chromosome number and the formulæ of each of these species supports this very strongly. The chromosomes throughout these species are all of a similar type, and the formulæ seem to show that these species (excluding *U. gracilis*) would be tetraploids if *U. gracilis* and *U. atrovirens* are taken as diploids. This suggests like *U. atrovirens* by somatic doubling or possibly by hybridisation of two forms like *U. gracilis* and *U. atrovirens*. Weddell states that *U. gracilis* Ait. is *Ŭ. dioica* the possibility of the origin of these forms from a type var. *procera*, but it is given as a distinct species in Gray's New Manual of Botany (New York 1908). Its chromosomes are very similar morphologically to those of *U. dioica* and its other varieties, but it has 26 chromosomes instead of 52. A single aneuploid plant of *U. gracilis* with 2n = .27 chromosomes was found. In this plant a tendency to form polyploid cells was noticed. Several of these with 54 chromosomes were encountered. A tetraploid could arise from such an aneuploid by somatic doubling and subsequent loss of the extra chromosomes. The presence of the extra chromosomes in the aneuploid seemed to have altered the stability of the whole set of chromosomes. Subsequent elimination of them from polyploid cells would not then be unlikely, and would be to the advantage of the whole complement. There is no evidence of the origin of these forms by hybridisation of two diploid forms, but that it is not unlikely is shown by the occurrence of a common haploid formula of 2A, 6B, 5C throughout the 26- and 52-chromosomed types with small chromosomes

Weddell and Engler put *U. pilulifera* and its varieties in a separate group. This is supported here. The chromosomes of these species are obviously of a different type from the other species, as is also shown by their formulæ 4A, 6B, 3C.

Urtica membranacea by its number stands alone among the species. Its formula A, 8B, 2C differs considerably from all the others. It is characterised by the possession of two large sub-terminally constricted chromosomes and a large satellited pair. It is placed in a separate sub-section of section 2 in the classifications.

The cytological evidence, on the whole, thus confirms the Classification of the genus according to Weddell, and except for the inclusion of *U. urens* and *U. atrovirens* in the same group, according also to Engler. Little information can be obtained from the geographic distribution of these species. The lower chromosomed species, however, excluding the *pilulifera* group, seem to be more local in their distribution, while the tetraploid forms of *U. dioica* cover a very wide area. The diploid variety of *U. dioica* (*U. gracilis*) is confined to America and also occurs in Mexico, but at an altitude of 2,400 m. *U. dioica* and its varieties thus cover the whole of the Northern temperate regions. *U. pilulifera* covers a wide area from the Mediterranean across to Northern Africa and into Southern Asia. *U. kioviensis* inhabits Southern Russia, while *U. cannabina* reaches as far as Persia; the former variety is purely local. This suggests that the small-chromosomed tetraploids are more cosmopolitan in their habitats, while the large chromosomed forms prefer more Southern regions.

This investigation has been carried out in the Department of Botany, Armstrong College, Newcastle-on-Tyne. I wish to thank Professor J. W. Heslop Harrison for facilities for carrying out the work, and also Dr. K. B. Blackburn for her constructive criticisms.

SUMMARY

1. Somatic chromosome numbers are given as follows:— *Urtica urens*=24; *U. atrovirens, pilulifera, Dodartii, balearica, gracilis*=26; U. *cannabina, dioica, kioviensis,* and the var. *angustifolia*=52; *U. membranacea*=22.
2. Chromosome formulæ have been obtained by placing the chromosomes in size classes.
5. Primary constrictions are median or sub-terminal or there may be none visible. *U. pilulifera* and its varieties possess two pairs of chromosomes which have secondary constriction. *U. membranacea* has a satellited pair.
6. Chromosome numbers and morphology support Weddell's classification of the genus, especially in the separation of *U. urens* from *U. atrovirens*.
7 The formulæ indicate that, in the types with small chromosomes, the species with 26 are diploid and those with 52 are tetraploid.

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THE MATRIX TREATMENT OF SOME PHYSICAL PROBLEMS.

by

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Within recent years, the physicist has become acquainted with, and, perhaps, reconciled to, those strange mathematical entities, matrices, which appear in modern quantum mechanics. Previously, the use of matrices in mathematical physics, has been very limited. Minkowski showed how convenient the matrix notation is for the formulation of the special theory of relatively. Matrix theory has not usually been part of the mathematical equipment of the physicist although in many branches of physics it is of great value. In the following pages the author has considered some old physical problems which lend themselves to this kind of treatment, with the object of showing how convenient it is.

Interacting circuits.

Consider a number n of circuits of resistances R_1 R_2 . . . R_n, self-inductances L_{11}, L_{22}, L_{33} . . . L_{nn} and containing E.M.F.s. E_1 E_2 . . . E_n. Let the coefficient of mutual induction for the pth and qth circuit be L_{pq}. Obviously $L_{pq} = L_{qp}$.
The number of tubes of induction through the pth circuit is

$$N_p = L_{p1}\, i_1 + L_{p2}\, i_2 \dots + L_{pp}\, i_p \dots + L_{pn}\, i_n$$

where i_p is the current in the pth circuit.

The whole of the n equations for the individual circuits can be conveniently expressed in matrix form as $N = LI$

where $N = \begin{vmatrix} N_1 \\ N_2 \\ \cdot \\ \cdot \\ \cdot \\ N_n \end{vmatrix}$; $I = \begin{vmatrix} i_1 \\ i_2 \\ \cdot \\ \cdot \\ \cdot \\ i_n \end{vmatrix}$; $L = \begin{vmatrix} L_{11} & L_{12} & L_{13} & \dots \\ L_{21} & L_{22} & L_{23} & \dots \\ L_{31} & L_{32} & L_{33} & \dots \\ \cdot & \cdot & \cdot & \dots \end{vmatrix}$

When the currents are varying we have for the p^th^ circuit $E_p - \frac{dN_p}{dt} = R_{pp}\, i_p$. The matrix equation for the whole of the n circuits is therefore

$$L\frac{dI}{dt} + RI = E \qquad R = \begin{vmatrix} R_{11} & O & O & \cdot & \cdot & \cdot \\ O & R_{22} & O & \cdot & \cdot & \cdot \\ O & O & R_{33} & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{vmatrix}$$

$$E = \begin{vmatrix} E_1 \\ E_2 \\ \cdot \\ \cdot \\ \cdot \\ E_n \end{vmatrix}$$

To solve this matrix equation write

$$RI - E = U.$$

$$\therefore \quad R\frac{dI}{dt} = \frac{dU}{dt}$$

$$\therefore \quad LR^{-1}\frac{dU}{dt} + U = O$$

. If det. $L \neq 0$ the matrix L has a reciprocal.

$$\therefore \quad \frac{dU}{dt} + RL^{-1}U = \frac{dU}{dt} + AU = O \qquad \text{where } A = RL^{-1}$$

$$\therefore \quad U = e^{-At}U_0$$

or $(RI - E) = e^{-At}(RI_0 - E)$. where I_0 is the initial current matrix.

The matrix function e^{-At} can be expressed in a simpler form. The characteristic numbers of the matrix A are the roots of the equation

$$\text{Det.}\begin{vmatrix} (A_{11}-\kappa) & A_{12} & A_{13} & \cdot & \cdot \\ A_{21} & (A_{22}-\kappa) & A_{23} & \cdot & \cdot \\ A_{31} & A_{32} & (A_{33}-\kappa) & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \end{vmatrix} = O$$

or $\kappa^n + P_1\kappa^{n-1} + P_2\kappa^{n-2} \ldots\ldots + P_n = O$

The Hamilton-Cayley Theorem states that the matrix A itself satisfies this equation. Thus

$$A^n + P_1A^{n-1} + P_2A^{n-2} \ldots\ldots + P_n = O$$

Making use of this result we can express A^n in terms of A^{n-1}, $A^{n-2} \ldots A$ and constants which depend on A and consequently any power of $A \geqslant n$ can be so expressed. It follows from this that e^{-At} can be expressed in terms of $A, A^2 \ldots A^{n-1}$ thus

$$e^{-At} = t_0 + t_1 A + t_2 A^2 \ldots + t_{n-1} A^{n-1} \qquad \text{—— (1)}$$

where the t's are functions of the time to be found. Differentiating (1) with respect to t gives

$$-Ae^{-At} = \frac{dt_0}{dt} + \frac{dt_1}{dt} A \ldots + \frac{dt_{n-1}}{dt}. A^{n-1} \qquad \text{—— (2)}$$

$$\begin{aligned} \text{But} -Ae^{-At} &= -A\,(t_0 + t_1 A \ldots t_{n-1} A^{n-1}) \\ &= -A\,(t_0 + t_1 A \ldots + t_{n-2} A^{n-2}) \\ &\quad - t_{n-1}\,(-P_1A^{n-1} - P_2A^{n-2} \ldots - P_n) \text{—— (3)} \end{aligned}$$

Equating Coeffs. of A^s on the right hand side of (2) & (3).

$$\frac{dt_0}{dt} = t_{n-1} P_n$$

$$\frac{dt_1}{dt} = t_{n-1} P_{n-1} - t_0$$

$$\ldots = \ldots\ldots$$

$$\frac{dt_\kappa}{dt} = t_{n-1} P_{n-\kappa} - t_{\kappa-1}$$

$$\ldots = \ldots\ldots$$

$$\frac{dt_{n-1}}{dt} = t_{n-1} P_1 - t_{n-2}$$

From this set of equations it can easily be shown that

$$\frac{d^n t_0}{dt^n} - P_1 \frac{d^{n-1} t_0}{dt^{n-1}} + P_2 \frac{d^{n-2} t_0}{dt^{n-2}} \ldots\ldots + (-1)^n P_n = O$$

Assume $t_0 = e^{\alpha t}$

$$\therefore \alpha^n - P_1 \alpha^{n-1} + P_2 \alpha^{n-2} \ldots\ldots + (-1)^n P_n = O$$

Hence the α's must be the minus of the characteristic numbers of the matrix A.

We have then

$$t_0 = \Sigma C_\kappa e^{\alpha_\kappa t} \quad \text{where the } C_\kappa \text{ are coefficients to be found.}$$

$$t_{n-t} = \frac{1}{P_n} \Sigma \alpha_\kappa C_\kappa e^{\alpha_\kappa t}$$

$$t_{n-2} = P_1 t_{n-1} - \frac{dt_{n-1}}{dt}$$

$$= \frac{P_1}{P_n} \Sigma \alpha_\kappa C_\kappa e^{\alpha_\kappa t} - \frac{1}{P_n} \Sigma \alpha_\kappa^2 C_\kappa e^{\alpha_\kappa t}$$

etc.

Since $e^{-At} \to 1$ as $t \to 0$ we must have, as $t \to 0$, $t_0 \to 1$ and $t_1, t_2 \ldots\ldots$ etc. $\to 0$.

$$\therefore \quad \Sigma C_\kappa = 1$$

$$\Sigma \alpha_\kappa C_\kappa = 0$$

$$\Sigma \alpha^2_\kappa C_\kappa = 0$$

$$\cdots \quad \cdots\cdots\cdots\cdots$$

$$\Sigma \alpha^{n-1}_\kappa C_\kappa = 0$$

These equations written in full are

$$C_1 + C_2 \ldots\ldots + C_n = 1.$$

$$\alpha_1 C_1 + \alpha_2 C_2 \ldots + \alpha_n C_n = 0.$$

$$- \quad - \quad - \quad - \quad - \quad - \quad -$$

$$\alpha_1^{n-1} C_1 + \alpha_2^{n-1} C_2 \ldots + \alpha_n^{n-1} C_n = 0.$$

giving C_p, $(p = 1, 2, \ldots\ldots n)$

$$= \frac{\begin{vmatrix} 1 & 1 & - - - & 1 & 1 & 1 & - - - & 1 \\ \alpha_1 & \alpha_2 & - - - & \alpha_{p-1} & 0 & \alpha_{p+1} & - - & \alpha_n \\ - & - & - - & - & - & - & - - & - \\ \alpha_1^{n-1} & \alpha_2^{n-1} & - - & \alpha_{p-1}^{n-1} & 0 & \alpha_{p+1}^{n-1} & - - & \alpha_n^{n-1} \end{vmatrix}}{\begin{vmatrix} 1 & 1 & - - - & 1 & 1 & 1 & - - - & 1 \\ \alpha_1 & \alpha_2 & - - - & \alpha_{p-1} & \alpha_p & \alpha_{p+1} & - - & \alpha_n \\ - & & - - & - & - & - & - - & - \\ \alpha_1^{n-1} & \alpha_2^{n-2} & - - - & \alpha_{p-1}^{n-1} & \alpha_p^{n-1} & \alpha_{p+1}^{n-1} & - - - & \alpha_n^{n-1} \end{vmatrix}}$$

Reverse the order of the columns so that the n^{th} becomes first, the (n—1)th second and so on in both numerator and denominator.

The denominator can then be written as the product of the following terms

$$
\begin{array}{r}
(\alpha_n-\alpha_{n-1})(\alpha_n-\alpha_{n-2})\ldots(\alpha_n-\alpha_{p+1})(\alpha_n-\alpha_p)(\alpha_n-\alpha_{p-1}) \\
(\alpha_n-\alpha_1) \\
(\alpha_{n-1}-\alpha_{n-2})\ldots.(\alpha_{n-1}-\alpha_{p+1})(\alpha_{n-1}-\alpha_p)(\alpha_{n-1}-\alpha_{p-1}) \\
(\alpha_{n-1}-\alpha_1) \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
(\alpha_{p+1}-\alpha_p)(\alpha_{p+1}-\alpha_{p-1})\ldots.(\alpha_{p+1}-\alpha_1) \\
(\alpha_p-\alpha_{p-1})(\alpha_p-\alpha_1) \\
\ldots\ldots\ldots\ldots\ldots\ldots \\
(\alpha_2-\alpha_1)
\end{array}
$$

The numerator is obtained from this by putting $\alpha_p=0$. All terms not containing α_p cancel in numerator and denominator giving

$$
C_p=\frac{\alpha_n\,\alpha_{n-1}\ldots.\alpha_{p+1}\,\alpha_{p-1}\ldots.\alpha_1}{(\alpha_n-\alpha_p)(\alpha_{n-1}-\alpha_p)\ldots(\alpha_{p+1}-\alpha_p)(\alpha_{p-1}-\alpha_p)\ldots(\alpha_1-\alpha_p)}
$$

$$
=-\frac{\Pi\alpha}{\alpha_p\,f'(\alpha_p)}\text{ where }f(\alpha)=(\alpha_n-\alpha)(\alpha_{n-1}-\alpha)\ldots(\alpha_p-\alpha)\ldots(\alpha_1-\alpha)
$$

$$
\Pi\alpha=\alpha_n\,\alpha_{n-1}\ldots.\alpha_p\ldots.\alpha_1
$$

Example.

Take the case of two circuits containing E.M.F.'s, E_1, E_2 and having resistances R_1, R_2, self-inductances L_1, L_2 and mutual inductance M.

$$
L=\begin{vmatrix} L_1 & M \\ M & L_2 \end{vmatrix}\;;\quad R=\begin{vmatrix} R_1 & 0 \\ 0 & R_2 \end{vmatrix}
$$

$$
A=RL^{-1}=\begin{vmatrix} \dfrac{R_1L_2}{L_1L_2-M_2} & -\dfrac{R_1M}{L_1L_2-M^2} \\ -\dfrac{R_2M}{L_1L_2-M^2} & \dfrac{R_2L_1}{L_1L_2-M^2} \end{vmatrix}
$$

The characteristic numbers of A are α_1, α_2 say and both positive. It is found that

$$e^{-At} = \frac{\left(\alpha_1 e^{-\alpha_2 t} - \alpha_2 e^{-\alpha_1 t}\right) + \left(e^{-\alpha_1 t} - e^{-\alpha_2 t}\right) A}{\alpha_1 - \alpha_2}$$

and $RI = E + e^{-At} (RI_0 - E)$.

If, initially, the currents are zero i.e. $I_0 = 0$, then I_1 and I_2 being the currents, at time t, in the primary and secondary circuits, we have at once

$$R_1 I_1 = E_1 + \frac{\alpha_1 e^{-\alpha_2 t} - \alpha_2 e^{-\alpha_1 t}}{\alpha_1 - \alpha_2} (-E_1)$$
$$+ \frac{e^{-\alpha_1 t} - e^{-\alpha_2 t}}{\alpha_1 - \alpha_2} \left(-\frac{R_1 L_2 E_1}{L_1 L_2 - M^2} + \frac{R_1 M E_2}{L_1 L_2 - M^2}\right).$$

$$R_2 I_2 = E_2 + \frac{\alpha_1 e^{-\alpha_2 t} - \alpha_2 e^{-\alpha_1 t}}{\alpha_1 - \alpha_2} (-E_2)$$
$$+ \frac{e^{-\alpha_1 t} - e^{-\alpha_2 t}}{\alpha_1 - \alpha_2} \left(-\frac{R_2 M E_1}{L_1 L_2 - M^2} + \frac{R_2 L_1 E_2}{L_1 L_2 - M^2}\right).$$

In the case of a pair of circuits for which det. $L = 0$ the matrix L^{-1} does not exist. From the original equation

$$L_{11} \frac{dI_1}{dt} + L_{12} \frac{dI_2}{dt} + R_1 I_1 = E_1$$

$$L_{21} \frac{dI_1}{dt} + L_{22} \frac{dI_2}{dt} + R_2 I_2 = E_2$$

since $L_{11} L_{22} - L_{12} L_{21} = 0$, we obtain

$$L_{22} R_1 I_1 - L_{12} R_2 I_2 = L_{22} E_1 - L_{12} E_2.$$

I_2 can be eliminated from one of the above equations by using this last relation and we have a differential equation in I_1 only.

Radioactive transformations.

Let P_0, P_1, P_2 . . . . be the masses of the various substances with P_0 changing into P_1, P_1 into P_2 etc. If λ_0 λ_1 etc. are the decay constants the state of affairs at the time t is given by the set of equations

$$\frac{dP_0}{dt} = \qquad - \lambda_0 P_0$$

$$\frac{dP_1}{dt} = \lambda_0 P_0 - \lambda_1 P_1$$

$$\frac{dP_2}{dt} = \lambda_1 P_1 - \lambda_2 P_2 \text{ etc.}$$

$$\cdots \quad \cdots\cdots$$

$$\frac{dP_n}{dt} = \lambda_{n-1} P_{n-1} - \lambda_n P_n \ .$$

If P_n is stable $\lambda_n = 0$.

The above set of equations can be written in matrix form as $\dot{P} = \lambda P$ where

$$P = \begin{vmatrix} P_0 \\ P_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ P_n \end{vmatrix} \; ; \; \lambda = \begin{vmatrix} -\lambda_0 & 0 & 0 & 0 & . & . \\ \lambda_0 & -\lambda_1 & 0 & 0 & . & . \\ 0 & \lambda_1 & -\lambda_2 & 0 & . & . \\ 0 & 0 & \lambda_2 & \lambda_3 & . & . \\ . & . & . & . & . & . \end{vmatrix}$$

Notice that the characteristic numbers of λ are

$- \lambda_0 \, , - \lambda_1 \, , \ldots\ldots \quad - \lambda_n$.

The solution of $\dot{P} = \lambda P$ is

$P = e^{\lambda t} p$ where P, p, are the matrices representing the mass distributions at times $t = t$ and $t = 0$. We can write

$$P = S^{-1} (S e^{\lambda t} S^{-1}) Sp$$

where S is a matrix chosen so that $Se^{\lambda t}S^{-1}$ is diagonal i.e. so that $S\lambda S^{-1}$ is diagonal and equal to D. The elements of D will be $-\lambda_o$, $-\lambda_1$, . . . etc.
S and S^{-1} are easily found to be

$$S = \begin{vmatrix} 1 & 0 & 0 & 0 & \ldots\ldots \\ \dfrac{\lambda_0}{\lambda_0 -- \lambda_1} & 1 & 0 & 0 & \ldots\ldots \\ \dfrac{\lambda_1\ \lambda_0}{(\lambda_1-\lambda_2)(\lambda_0-\lambda_2)} & \dfrac{\lambda_1}{\lambda_1-\lambda_2} & 1 & 0 & \ldots\ldots \\ \cdot\quad\cdot & \cdot\quad\cdot & \cdot & \cdot & \cdot \end{vmatrix}$$

$$S^{-1} = \begin{vmatrix} 1 & 0 & 0 & 0 & \ldots\ldots \\ \dfrac{\lambda_0}{\lambda_1-\lambda_0} & 1 & 0 & 0 & \ldots\ldots \\ \dfrac{\lambda_1\ \lambda_0}{(\lambda_2-\lambda_0)(\lambda_1-\lambda_0)} & \dfrac{\lambda_1}{\lambda_2-\lambda_1} & 1 & 0 & \ldots\ldots \\ \cdot\quad\cdot & \cdot\quad\cdot & \cdot & \cdot & \cdot \end{vmatrix}$$

whence $P = S^{-1}\, e^{Dt}\, S\, p.$

The amount of any substance present at time t can be written down immediately. Thus for the substance corresponding to the suffix κ

$$\begin{aligned} P_\kappa &= \sum_{lm}(S^{-1})_{\kappa l}\; e^{-\lambda_l t}\; S_{lm}\, p_m \\ &= \frac{\lambda_{\kappa-1}\,\lambda_{\kappa-2}\ldots\lambda_o}{(\lambda_\kappa-\lambda_o)(\lambda_{\kappa-1}-\lambda_o)\ldots(\lambda_1-\lambda_o)}\, e^{-\lambda_o t}\,(p_o) \\ &+ \frac{\lambda_{\kappa-1}\ldots\ldots\lambda_1}{(\lambda_\kappa-\lambda_1\ldots(\lambda_2-\lambda_1)}\, e^{-\lambda_1 t}\left(\frac{\lambda_o}{\lambda_o-\lambda_1}\,p_0+p_1\right) \\ &+ \frac{\lambda_{\kappa-1}\ldots\lambda_2}{(\lambda_\kappa-\lambda_2\ldots\ldots(\lambda_3-\lambda_2)}\, e^{-\lambda_2 t}\left(\frac{\lambda_1\,\lambda_0}{(\lambda_1-\lambda_2)(\lambda_o-\lambda_2)}\,p_o \right. \\ &\qquad\qquad \left. +\frac{\lambda_1}{\lambda_1-\lambda_2}\,p_1+p_2\right) \\ &+ \text{etc.} \end{aligned}$$

Since $P = S^{-1} e^{Dt} Sp$

$\therefore SP = e^{Dt} Sp$

and $(SP)_n = e^{-\lambda_n t} (Sp)_n$

$\therefore$ The quantity of radioactive material $(SP)_n$ behaves as though it had a transformation constant λ_n.

General.

In the previous sections the equations dealt with are particular cases of the following more general one. Consider the set of *n* linear equations of which the pth is

$$a_{p1}\frac{dx_1}{dt} + a_{p2}\frac{dx_2}{dt} \ldots\ldots + a_{pn}\frac{dx_n}{dt}$$

$$+ b_{p1}x_1 + b_{p2}x_2 \ldots\ldots\ldots + b_{pn} x_n = f_p$$

where the a's and b's are constants and the f's may be functions of t.

In the matrix form the set can be written as

$$A\frac{dX}{dt} + BX = F \quad \text{where}$$

$$A = \begin{vmatrix} a_{11} & a_{12} & \ldots \\ a_{21} & a_{22} & \ldots \\ \ldots & \ldots & \ldots \end{vmatrix}; B = \begin{vmatrix} b_{11} & b_{12} & \ldots \\ b_{21} & b_{22} & \ldots \\ \ldots & \ldots & \ldots \end{vmatrix}; X = \begin{vmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \end{vmatrix}; F = \begin{vmatrix} f_1 \\ f_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \end{vmatrix}$$

Assuming det. $(A) \neq 0$ so that A has a reciprocal A^{-1} the equation can be solved by using a matrix integrating factor $\mu = e^{A^{-1}Bt}$

$$\text{This gives } \frac{d}{dt}(\mu X) = \mu A^{-1}F$$

$$\mu X - X_0 = \int_0^t \mu A^{-1} F\, dt$$

$$\text{or } X = e^{-A^{-1}Bt}\left[X_0 + \int_0^t \mu A^{-1} F dt\right]$$

where X_0 is value of X at t=0.

$e^{-A^{-1}Bt}$ can be treated by the method adopted earlier in this paper.

If det. $A = o$ the method fails as A^{-1} does not exist. In this case relations hold among the rows and columns of A. If A is of rank r then only r rows and columns of A are linearly independent (see "*The Theory of determinants, matrices and invariants*" H. W. Turnbull, page 73). Let these be the first r rows and r columns.

Then if $r < s \lessapprox n$

$$\text{row}_s = \lambda_{s1}\,\text{row}_1 + \lambda_{s2}\,\text{row}_2 + \ldots\ldots\ldots + \lambda_{sr}\,\text{row}_r$$

where the λ's are suitably chosen constants. These conditions amount to the following. If the matrix A is divided into two sub-matrices by a section between the r^{th} and $(r+1)^{th}$ rows, thus

$$A = \begin{vmatrix} A_1 \\ \cdots\cdots \\ A_2 \end{vmatrix}$$

then $A_2 = \lambda A_1$ where λ is the matrix

$$\begin{vmatrix} \lambda_{(r+1)1} & \lambda_{(r+1)2} & \cdots\cdots\cdots & \lambda_{(r+1)r} \\ \cdot & \cdot & \cdot & \cdot \\ \lambda_{n1} & \lambda_{n2} & & \lambda_{nr} \end{vmatrix}$$

The original matrix equation can be written

$$\begin{vmatrix} A_1 \\ \cdots\cdots \\ \lambda A_1 \end{vmatrix} \frac{dX}{dt} + \begin{vmatrix} B_1 \\ \cdots\cdots \\ B_2 \end{vmatrix} X = \begin{vmatrix} F_1 \\ \cdots\cdots \\ F_2 \end{vmatrix}$$

where the matrices B and F have been divided into sub-matrices in the same way as A. We now have

$$A_1 \frac{dX}{dt} + B_1X = F_1$$

$$\lambda A_1 \frac{dX}{dt} + B_2X = F_2$$

whence

$$(\lambda B_1 - B_2)X = \lambda F_1 - F_2.$$

This matrix equation represents (n—r) ordinary linear equations in $x_1\, x_2 \ldots\ldots x_n$ and other quantities. These equations can be used to express $x_{(r+1)} \ldots\ldots\ldots x_n$ in terms of $x_1 \ldots\ldots\ldots\ldots x_r$ and so the original n equations can be reduced to r. The solution of these equations can be carried out as before.

DETERMINISM AND PHYSICS.

by

BERTRAND RUSSELL.

Ever since the time of Descartes' immediate followers, and more especially since the time of Newton, it has been held by physicists that the motions of matter, at any rate when it is not living matter, are rigidly in accordance with certain laws such that, given sufficient data concerning some finite period of time, however short, a mathematician of adequate skill could exactly calculate the whole of the past and the future. For religious reasons, some physicists have made an exception as regards the bodies of live animals, or at any rate of human beings. Speech, for example, consists of bodily movements, and people found it unpleasant to suppose that all they said was determined by the laws of physics, and not by their thoughts. Apart, however, from this possible realm of freedom, determinism in physics was unquestioned for nearly three centuries.

Under the influence of quantum physics, certain men of science, of whom, in England, Eddington is the chief, have begun to throw doubt on this principle, and have thus raised anew a question of the gravest importance which was thought to have been definitively answered. My purpose in what follows will not be to answer the question, but to make it precise, and to consider the nature of the evidence, actual and possible, on either side.

In classical physics, determinism was easily defined. Matter was supposed to be real, and to be really moving about. Physical observations determined the positions of the planets and their satellites. The law of gravitation made it possible to calculate, not only theoretically, but practically, the future positions of these heavenly bodies, and observation confirmed the results of calculation. In popular imagination, the discovery of Neptune through the perturbations of Uranus set the seal on this astronomical determinism. It was confidently inferred that other phenomena were equally calculable by means of other laws, though the laws might be more complicated and the calculations more difficult. Laplace's calculator, who, at the time of the primitive nebula, foresaw the whole development of the cosmos, was held to be a possible being, though one possessed of more mathematical skill than falls to the lot of men.

Modern physical theories have made this point of view in many ways inadequate. Not only has it become less apparently certain that determinism is true, but it is now much more difficult to give a definite meaning to determinism, especially if it is limited to dead matter. Clearly our first problem must be to define the issue, since nothing is more prolific of fruitless controversy than an ambiguous question.

The question of determinism may be considered both practically and theoretically. Practically, it is found in experiments on atoms that, when all possible care has been taken to make the relevant circumstances the same on two occasions, the outcome may nevertheless be different; it therefore becomes a debateable question whether, in time, differences hitherto unobserved will be found to account for the differences in the result. As a practical experimenter's principle, determinism says: "when two experiments give different results, there is some discoverable difference in the conditions; and when all discoverable conditions are identical, the outcome is identical." I say "discoverable" because, if it were necessary to invent hypothetical differences which could not be observed, the principle would tell us nothing, since any imaginable course of nature would conform to it.

To state the issue of determinism in its theoretical form, in a manner applicable to modern physics, it is necessary first to define determinism as an abstract doctrine, and then to consider some of the ways in which the concepts of quantum mechanics differ from those of the classical system.

Determinism, as an abstract doctrine, states that there are laws by which events at one time can be inferred from events at other times. In practice, its opponents assume this to be true just as much as its advocates do. When they see a printed book, they feel quite sure that some one wrote it and had it printed; it never occurs to them as possible that their present visual sensation has arisen spontaneously. When they hear others arguing against them, they do not doubt that the unpleasant noises which they perceive express the thoughts of human beings. They believe in the past as recorded in history. They believe that writing to a bookseller for a book will produce a book, and writing to a wine merchant for wine will produce wine. None of us could exist without assuming that the course of nature and human activity is regulated by causal laws.

But this somewhat vague and general belief became defined, during the seventeenth century, into the doctrine that everything can be reduced to matter and motion, and that the ultimate causal laws are those of Newtonian dynamics. This view can no longer be upheld; but whether determinism need be abandoned is another question.

Modern theoretical physicists have no belief in persistent pieces of matter, or in space in any straightforward sense; they have many local times instead of one cosmic time, and some of their laws violate continuity. They try to state their theories in terms of what they call "observables"—a more difficult conception than they perhaps realise, and one which I shall shortly discuss.

A few references will serve to introduce the modern point of view. Heisenberg, in first proposing his atom in place of Bohr's, pointed out that the latter used unobservable quantities, such as the position and time of revolution of an electron, but that it is desirable to represent the electron by means of measurable quantities, such as the frequencies of radiations. He went on to say that we cannot, by means of observable quantities, allocate a definite position in space to an electron at each moment of time. (Ueber quantentheoretische Umdeutung kinematischer u. mechanischer Beziehungen. Zeitschrift für Physik, 33,pp. 879-893, 1925). That is to say, since the electron is only observable when it emits radiation, we must say nothing whatever about what it does at other times, and must not even assume that it exists between explosions. Born & Jordan (in the next volume of the same journal, still 1925) say that whereas, in the older theory, quantum paths have an order from the start, the new mechanics presents itself as a true discontinuity-theory, and the quantum numbers are nothing but distinguishing indices, which can be ordered by practical considerations. Born (Vol. 35, 1926) says that we shall not master the difficulties of quantum-mechanics until we have a mathematical system of relations between observable magnitudes as simple and unified as the system of classical mechanics; but this new system will have the defect that it cannot be interpreted by geometrical intuition, since movements of electrons cannot be described in the usual space and time. In a popular article (Naturwissenschaften, 14 Jahrgang, Heft 45, pp.989-994), Heisenberg says "electrons and protons do not have the degree of immediate reality of objects of daily experience." "It is not possible," he says, "to assign to a corpuscle a determinate place as a function of the time, but we can assign to it a collection of radiation-quantities . . . It is moreover in principle impossible to identify again a particular corpuscle among a series of similar corpuscles." Even time needs a re-interpretation of which the nature is not yet clear. "The question of the temporal course of a process," Heisenberg says (Math. Annalen 95, 1926, p.705), "has no immediate meaning, and the concept of earlier and later can hardly be defined exactly . . . . . . The appearance of just such difficulties was to be expected from the nature of the space-time relations that hold for atomic systems."

These quotations make it clear that the conceptions of matter and motion, which form the basis of the technical apparatus of classical physics, have been abandoned, not only philosophically, but technically. An electron has become a set of radiations, and has no persistent identity such as is required for the idea of motion. The events which are called "observables" do not take place in ordinary space and time, whether Euclidean or relativistic. The laws of quantum mechanics, therefore, are so different from those of classical physics that the deterministic hypothesis must be stated in quite new terms.

The change which has come over our conception of the physical world is so great that some reputable writers, with the glee of children escaping from school, proclaim "the end of mechanistic physics."* By "mechanistic" these men mean "having to do with matter in motion." But that is an interpretation of mechanism which ties it unnecessarily to an antiquated technique. The essence of mechanism, as a concept, is the existence of mathematical formulae by which events can be inferred from other events; and this may still be possible, though it requires a new technique. The old technique of matter in motion, which comes from Galileo, works with the concepts of substance, space, and time. Philosophically, it has been out of date since Berkeley; in our day, at last, mathematical technique has caught up with that admirable Bishop. It has, I must admit, gone even beyond him in one respect, namely as regards time; but this advance appears more in relativity than in quantum theory. I think myself that time, even in relativity theory, is still too conventional, being still supposed to consist of instants, of whose existence (in the logical sense) I am by no means convinced. But that is a separate issue, which, for our present purpose, may be ignored.

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*See Philipp Frank, "Das Ende des Mechanistischen Physik," Einheitswissenshaft, Heft 5, Vienna, 1935.

Substance, as something persisting through time, still survived in Bohr's original introduction of the quantum into atomic theory. He retained Rutherford's electrons revolving about a nucleus like planets going round the sun; his innovation consisted in confining the electrons to a certain discrete series of orbits, and making the transitions from one orbit to another sudden and discontinuous. It is only at these moments of transition that the atom emits energy. This fact lead Heisenberg to introduce a more startling novelty. The only moment at which an atom has any external effect is the moment in which it emits (or absorbs) energy: and when it has no external effect it cannot be observed. What is essentially and theoretically incapable of being observed is a mere metaphysical abstraction, which the man of science should discard. Therefore there is no reason to suppose that the atom exists except when it is emitting (or absorbing) energy. In Bohr's theory, the atom was usually in a stable condition, but suffered from occasional revolutions; in the new theory, the revolutions alone remain, and physics is silent as to what (if anything) exists between cataclysms. Thus substance has disappeared, and has been replaced by a staccato series of events. Space, also, is completely different from what it was in classical physics. But on this subject I shall say more at a later stage.

The first step in examining the philosophy of quantum physicists is to be clear as to what is meant by an "observable." This is a concept derived from the laboratory, not from daily life. I am inclined to think that elements of physical realism cling to it, to an extent of which the physicists are hardly aware. What they have in their imagination when they use the word is a laboratory with all the instruments of precision, and a scientific observer on the look-out for a measurable result of which he already knows the general character, though not the exact quantitative measure. At a certain moment, he has a perception which gives him a numerical value for some quantity in which he is interested. What he thus perceives is an "observable." The word suggests—whether intentionally or not—that the "observable" would exist even if he did not observe it, but we may avoid this suggestion by a suitable interpretation.

The object of the modern physicists is to avoid assumptions, as to matter, that lie outside experience. This is a laudable object, but by no means easily attained.

How does the word "observable" differ from the word "observed"? If we confine physics to what is actually observed, it will have, before it can formulate any laws, to deal with the actions of physicists, and to have means of calculating when they will be in their laboratories and when they will be eating their lunch. No doubt the *data* of physics are all actually observed, but the *laws* of physics are concerned with what *could be* observed, not only with what *is* observed. Therefore if we wish to keep as near as we can to actual experience, a physical law must be stated in the hypothetical form: "If I had looked, I should have seen so-and-so." This "so-and-so" is an observable; it is an event which (we are told) will take place if I make certain adjustments of my body and my scientific apparatus. And the event, of course, is in *me*.

Nevertheless an "observable" is assumed, in physics, to be something that anybody could observe, not something personal, like a dream or a toothache. What does this mean when reduced to what I can verify? It means that statements heard or read, but not spoken or written, by me, asserting the "observable," are themselves "observables." If these statements are regarded as evidence concerning the original observable, they must be supposed to express the experiences of others, which are not observable for me. Thus a large hypothetical element survives in the conception of an "observable."

The laws of physics, therefore, are now of the following sort: If, when my percepts and recollections are such as are suitable to a certain experiment, I act in a certain way, such as looking through a microscope, I shall have a percept of such and such a kind; and if I have the percepts which I should naturally interpret as another person looking through the microscope, and I make the noise "tell-me-what-you-see," I shall hear the same noise as I should have made if I had been looking through the microscope and had heard the noise "tell-me-what-you-see." The necessary refinements, such as the possibility of using French or German instead of English or writing instead of speech, bring in no question of principle, and may be ignored.

Such laws do not enable us to predict any actual event, unless they apply to our own acts. If they do not so apply, they do not tell us when we shall go into the laboratory, or what experiment we shall carry out there; and they tell us nothing about what goes on in the laboratory when we are not there, nor even that it exists at such times. So long as we ourselves are supposed free, the most complete determinism possible, with this interpretation of physics, merely tells us what our percepts will be if we go through certain preliminaries such as looking in a given direction. They do not tell us whether we shall look, or what (if anything) happens in the physical world when we are not looking.

Although the above must be taken to be the interpretation which physicists intend, their practice is somewhat different. A continuously existing world of observables is hypothetically constructed, and the observer is ignored, except on state occasions when some new phenomenon is recorded. The observables which might have been observed are treated as exactly on a level with those which were observed, and no physicist feels imaginatively any difference between the two. Realism still dominates the physicist practically: he *feels* that what he observes is outside himself, could be observed by many people, and would exist even if not observed. He knows, of course, that visual objects cannot exist apart from an eye and brain, but he supposes them to have an outside cause which shares at least some of the properties of their spatio-temporal structure. This supposition is not logically necessary; a solipsistic interpretation of physics is easily constructed as a logical exercise. But if this interpretation were taken seriously, physics would lose its emotional interest. The matter is important in connection with determinism, since, if we assume that from our sensations we can infer something as to their external causes, we are already committed to determinism. If physics deals with the *causes* of sensations, it must assume determinism as regards these causes, since otherwise it must collapse.

Leaving these philosophical questions of interpretation, let us examine the world of physics as it is presented in modern theory.

All modern views as to the structure of the atom rest upon the frequencies of radiations. A hydrogen atom, for instance, is the possibility of any one of a certain infinite series of frequencies, each associated with the difference of two integers; moreover, there are also, where a large number of hydrogen atoms are concerned, fixed statistical proportions between the number of atoms emitting radiation of one frequency and the number emitting radiation of another frequency, and also, in given circumstances, between the number emitting radiation and the number emitting none. There is, at present, nothing to show why an atom suddenly emits radiation at one moment more than another, nor why it chooses one possible frequency in preference to all the other possibilities. The space occupied by an atom is not ordinary space, and the atom does not move in any ordinary sense. On the other hand, the light-waves which the atom emits move respectably through an old-fashioned space, and do not become odd until they meet fresh matter. Owing to our statistical knowledge, we can predict the behaviour of large masses with a near approach to complete accuracy; but the behaviour of individual atoms is unpredictable, except that each atom can only do one of a certain number of definite things.

Two lines of argument are used by Eddington against determinism in physics. On the one hand, the known quantum laws do not suffice to determine when a quantum transition will take place, nor which of the various possible transitions it will be. On the other hand, what is called the " principle of indeterminacy " is said to show that a deterministic quantum physics is definitely impossible. I shall deal first with the second of these arguments.

Heisenberg's "principle of indeterminacy," in its simplest form, states that no quite definite numerical value exists either for the position or for the momentum of a particle, and that, as the margin of error in either is diminished, that in the other is increased. There is a range of uncertainty as to the value of the one, and another range of uncertainty as to the value of the other; the product of the two uncertainties in a given observation is constant, and equal to Planck's constant h. Thus the more accurately you determine where a particle is, the less accurately you will know how fast it is moving, and vice versa. Theoretically, the uncertainty as to position can be diminished indefinitely, but the uncertainty as to velocity will be proportionately increased; and if we set to work to get the velocity as accurate as possible, the position will grow vague.*

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* It should be said that Heisenberg's theory is not accepted by all physicists. Einstein, Podolsky, and Rosen published an article in the *Physical Review* (May 15, 1935) in which they maintained that the description of physical reality in modern quantum theory is incomplete; to this article, however, Bohr replied in a manner which seems convincing. On the other hand, Dr. N. S. Japolsky, in two articles in *The Philosophical Magazine* for September and October 1935, called " A Theory of Elementary Particles," maintains that all the experimental results in atomic theory can be explained in accordance with the principles of Maxwellian electrodynamics, without any fundamental novelty. I am not competent to judge as to the correctness of Dr. Japolsky's theory, but if it is valid it makes much recent speculation unnecessary.

Eddington's use of this principle to prove that physics cannot be deterministic seems to me to be fallacious. He says: " The velocity which we attribute to a particle now can be regarded as an anticipation of its future position. To say that it is unknowable (except with a certain degree of inaccuracy) is to say that the future cannot be anticipated. . . . The classical view that a particle necessarily has a definite (but not necessarily knowable) velocity now, amounts to disguising a piece of the unknown future as an unknowable element of the present. Classical physics foists a deterministic scheme on us by a trick; it smuggles the unknown future into the present, trusting that we shall not press an inquiry as to whether it has become any more knowable that way."*

There is so much to say in criticism of this passage that I hardly know where to begin. To take a small point first: in classical physics velocity never changes discontinuously, and therefore the velocity at an instant can be determined by observing the position at that instant and at other times all earlier than it; there is no need to anticipate the future except in the general assumption of continuity, without which the conception of velocity loses all meaning. In the second place, velocities need not, in classical mechanics, be any part of our data, which may be confined to observations of positions. But these remarks only apply to the older physics, and it is the new quantum physics that concerns us. As to this, Eddington himself, oddly enough, has given the complete answer in another part of the same book. He says: " When we encounter unexpected obstacles in finding out something which we wish to know, there are two possible courses to take. It may be that the right course is to treat the obstacle as a spur to further efforts; but there is a second possibility—that we have been trying to find something which does not exist. . . . From this point of view we assert that the description of the position and velocity of an electron beyond a limited number of places of decimals is an attempt to describe something that does not exist.* This, of course, supplies a refutation of the attempt to show that physics is not deterministic because it does not allow us to measure position and velocity accurately. Neither is an accurate conception; they have an inherent vagueness, like the conception of baldness. One might as well argue that the growth of the hair is not subject to natural law because we cannot determine precisely how many hairs a man must have in order not to be bald. One cannot blame physics for failure to measure what does not really exist.

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* " The Nature of the Physical World," p. 307.

Undoubtedly space has to have very different properties from those which Euclid ascribed to it; the days of the Kantian à priori intuition are very remote. A few words on space seem necessary at this point. A "space" may be defined as an infinite collection of terms ordered by means of some relation giving rise to what is called "neighbourhood" in topology. Perhaps we should add that a space must have more than one dimension. Empirically, there are first visual and tactual spaces, then the constructed space which contains all our sense-data at any one time, and then finally the space of physics. It is easy to confuse the constructed private space with physical space. For example, it is thought that what a physiologist sees when he examines another man's brain through a microscope is in the other man's brain, whereas, if we are talking of physical space, it is in the physiologist's brain. The whole of our sensible world is inside our head, when we are speaking of physical space. This is obvious as soon as we consider causation: light as dealt with in physics is outside our heads, but causes events in our heads, of which the last is seeing something.

If we want to eliminate the realist hypothesis implied, verbally at least, in the above account of physical space, we must put up with certain complications. An eclipse of the sun, for instance, is naturally conceived as something external to everybody, causing visual experiences in all who see it. But we can give a solipsistic account of it which will leave astronomy formally unchanged. I have a certain number of experiences which I connect with the eclipse: I see it, I hear noises which I interpret as others saying they saw it, I read accounts of it, and I see photographs of it. I collect all these, ante-dating some of them, and giving them the appropriate location in constructed physical space. A "cause," when it is nominally something outside experience, can always be taken to be a logical construct built out of actual experiences. The only spaces that are not constructs are those of the separate senses, especially sight and touch.

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* *Ibid.*, pp. 221-2.

In connection with the Principle of Indeterminacy, the importance of the above is that there can be no reason to expect physical space to have the smooth and comfortable punctuality assumed in geometry. Physical space has to be made to fit physical laws, and the introduction of discontinuity in quantum theory inevitably makes the old space no longer wholly adequate. There is therefore no reason to be surprised that position and velocity cannot be accurately attributed to an electron.

The principle of indeterminacy is explained by some writers—notably Niels Bohr—as a consequence of a simple fact in the technique of measurement. When a quantity is measured, there is an interaction between the measuring apparatus and what it measures, and this interaction necessarily impairs the accuracy of the result. Suppose, for example, we wish to measure the position and velocity of an atom: we can arrange our apparatus so as to give a measure of the one, or so as to give a measure of the other, but not both at once. Thus even if, in fact, the old deterministic laws of physics were true, we could never prove that they are. As Bohr puts it: "The finite interaction between object and measuring agencies conditioned by the very existence of the quantum of action, entails—

because of the impossibility of controlling the reaction of the object on the measuring instruments if these are to serve their purpose—the necessity of a final renunciation of the classical ideal of causality and a radical revision of our attitude towards the problem of physical reality."

The conclusion, here, seems to go beyond what is warranted by the data. What is proved is that, as we already knew in some other respects, so, in yet one more respect, measurement fails to tell us something about the object alone, and tells us, instead, something about its relation to the measuring apparatus. It is a commonplace that velocity and position are relative to the observer in so far as they can be observed; we now find that they are not merely severally, but jointly, relative. In this there is nothing very surprising, and certainly nothing to disprove the old idea of causality. Just as Einstein was able to adapt physics to one kind of relativity, so, it seems to me, the quantum theorists could, if they so desired, adapt it to a new kind. This seems, in fact, to be Bohr's own conclusion. The data of physics are not quite what they were supposed to be, but they are none the less data, and, so far as the principle of indeterminacy can show, they may be capable of fitting perfectly into a new deterministic scheme.

I come now to the second argument against determinism in physics, namely that the known laws do not determine what an individual atom will do, but only what will be the average distribution of behaviour among a large number.

This ignorance concerning the behaviour of single atoms may, at any moment, be dispelled. It is, after all, only recently that observations concerning single atoms have been possible, and it may be presumed that our knowledge is still incomplete. Descartes, knowing the conservation of *vis viva* but not of momentum, thought that the mind could influence the body by altering the direction, though not the amount, of the motion of the animal spirits. His followers, having to acknowledge the conservation of momentum, were led to a rigid determinism. Perhaps our present situation is similar.

There is a further point. Is statistical regularity possible if there is no regularity as regards the units of the statistics? This is a difficult question, which, so far as I know, has never been adequately discussed. It is connected with *probability*: we are supposed to know the probability of an atom doing this or that, but not whether it will in fact do this or do that. Can this be an ultimate analysis of physical laws?

The behaviour of atoms according to quantum theory may be illustrated by an analogy, which, however, must not be pressed beyond a point. In a swimming bath, you will often find a series of steps from which people can dive. They cannot dive except from one of the steps, so that divers are presented with a series of discrete possibilities. Bad divers (the majority) will choose the lowest step, slightly better ones the second step, and so on. Very few will choose the top step. The attendant, if he chose, could discover what percentage choose each step. If he were a quantum physicist, he might suppose that no causes whatever influenced the choice of an individual diver, and that the only causal laws concerned were the statistical laws as to the average behaviour of large numbers. This might seem a strange view, but it would be closely analogous to that which is being advocated as regards the behaviour of atoms.

Probability in general is an obscure conception, but in statistical cases it can be interpreted in accordance with what is called the "frequency theory." That is to say, when we have a class of objects of which a proportion p have a certain property, p is the chance that an object which is only known to belong to that class will have the property in question. This sort of probability is definable, not an independent concept; and this is the sort with which we are primarily concerned.

The question is this: If the behaviour of individual atoms is, in the relevant respects, quite haphazard, can it happen that there will be laws as to the statistical behaviour of large numbers? Eddington gives the example of life insurance. The insurance company cannot foresee whether A or B will die during the year, but can foresee, with tolerable accuracy, what proportion of the population will die. Similarly we know what proportion of a large number of radium atoms will disintegrate in a given time, though we do not know which atoms will do so. But in the case of the insurance company, we believe each individual death to be caused, and, if it were not, it is difficult to see what ground we should have for expecting regularity in the total. Probability always assumes a " random " distribution of something or other. But in a lawless world, why should the distribution be " random "? Is this itself an ultimate law? This seems absurd. It is true that there are arguments intended to prove that, in the absence of law, any other than a random distribution is " improbable." But if we pursue this line of reasoning to its logical termination, we shall be forced, in the end, to assume probability in a sense other than statistical frequency, and we shall find ourselves landed in some obscure mysticism. If we stick to frequency, we must not say that a non-random distribution is " improbable " unless there are laws regulating individual cases from which it can be deduced that non-random distributions seldom occur. I am inclined to conclude, therefore, though with some hesitation, that statistical regularity implies some kind of law regulating each particular case. If so, there must be hitherto undiscovered laws as to the behaviour of individual atoms, if the statistical laws are to be accepted as valid.

The hypothesis that the physical world is not deterministic is difficult to formulate correctly. It is admitted that macroscopic phenomena are deterministic, and the overwhelming majority of observables are macroscopic, the only exceptions being connected with a few delicate experiments in laboratories. Therefore *if* physics is really concerned with what can be observed, it is deterministic as regards all phenomena except a few in the very exceptional environment of a physical laboratory. Why are these few phenomena considered to be more informative than those of daily life? We must not give a realistic answer, since the physicists boast of confining themselves to observables. We cannot therefore say that the experiments upon which modern physical theory depends reveal more than ordinary observation as to what goes on in the outer world, since nothing observable reveals anything of the outer world. Nor can we say that they give us more power of prediction, if, as is contended, they are lawless, for in that case they give us less power of prediction than we can derive from macroscopic observations.

What we can say is the same as is to be said in favour of the microscope as opposed to the naked eye. Things that look alike to the naked eye may look different through the microscope, but not vice versa, and the differences may be associated with important causal differences—for example, between pure water and water containing bacteria. Apart from causation, there is no reason for preferring the microscope to the naked eye; if determinism is abandoned, the reasons for care in scientific observation are gone, since all these reasons are concerned with the attempt to discover causal laws.

Let us now sum up the foregoing argument. In the first place, physics, and science generally, is impossible unless determinism is preserved over a very large field. Apart from causal laws, no observation gives us the right to draw any inference whatever, either as to what others will observe, or as to what we shall observe at another time. Physics is distinguished from psychology through the hypothesis that sensations have causes: if this hypothesis is dropped, physics becomes a branch of psychology, and determinism in physics must stand or fall with determinism in psychology. Whether or not this conclusion is philosophically valid, it is certainly not intended by the quantum physicists, who would hate to have the most advanced of the sciences incorporated in the most backward. Quantum physicists admit, in fact, that macroscopic phenomena are deterministic. As regards occurrences in individual atoms, however, they find no evidence for the existence of causal laws sufficient to decide what will occur. Here their argument is not merely that such laws are not yet known, but that, in virtue of the principle of indeterminacy, they never can be known. This, if I am not mistaken, is a fallacy, arising from insufficient loyalty to their own innovations. What they have in fact proved is that conjugates such as position and momentum have no separate existence, but what does exist remains determinable. And as regards statistical laws, it is difficult to see how they can be valid in a world in which individual occurrences are completely haphazard.

I conclude that, while there is at present no decisive reason in favour of complete determinism in physics, there is no reason against it, and there are several reasons, not demonstrative, for regarding it as still the best working hypothesis. Determinism, whether universally true or not, is co-extensive with the sphere of possible scientific knowledge; where it fails, scientific knowledge fails. It is theoretically impossible that there should be actual reasons against it, because any finite set of events can, with sufficient ingenuity, be brought under a general law, in fact under an indefinite number of general laws. If a new experiment disproves all the laws hitherto suggested, there will still remain a multitude of possible laws not yet disproved. Causality, therefore, whether universal or not, is a suitable and unavoidable working hypothesis in all scientific investigation.

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THE NATURAL HISTORY OF THE ISLE OF RAASAY
AND OF THE ADJOINING ISLANDS OF SOUTH RONA, SCALPAY, FLADDAY, AND LONGAY.

Edited by

J. W. HESLOP HARRISON, D.SC., F.R.S.

THE GEOLOGY OF THE ISLAND OF RAASAY.

by

CHARLES F. DAVIDSON, B.Sc., F.R.S.E., F.G.S.

(Communicated by permission of the Director of The Geological Survey and Museum.)

The geology of the island of Raasay in the Inner Hebrides is singularly varied and attractive. Indeed, there are few areas of comparable size in Britain which exhibit such a diversity of scenery and geological structure. It is not surprising, therefore, that a considerable geological literature has arisen around this little island, and in the following description, prepared to accompany a number of reports by the Armstrong College, (University of Durham), Newcastle upon Tyne and University College, Dundee, Raasay Expeditions of 1934, 1935 and 1936, the writer has drawn freely upon these previous publications. For a more detailed account of the rock groups of the island, and for a history of their investigation, the reader is referred to a posthumous paper of H. B. Woodward[1] who undertook the first detailed mapping of the south of Raasay for the Geological Survey, to a memoir based on later mapping by G. W. Lee (with palæontological notes by S. S. Buckman)[2], and to a study by the writer on the Tertiary igneous rocks.[3] In these works will be found a full bibliography on the geology of the island.

Raasay has a surface area of approximately twenty-seven square miles, and is elongated in a northerly direction with a length of fourteen miles from Rudha nan Sgarbh, the northernmost promontory, to Rudha na Cloiche in the south, the breadth of the island from east to west ranging irregularly from three miles at Ósgaig to half a mile near Arnish. It is separated from the adjacent island of Skye on the west by the Sound of Raasay, from one to nearly five miles wide, and from the mainland district of Applecross six to ten miles away by the Inner Sound. On the north, cut off by a swiftly-flowing kyle less than a mile broad, is the island of South Rona, also studied by various parties from the two Colleges.

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[1] "Notes on the Geology of Raasay," *Trans. Edin. Geol. Soc.*, vol. x, p 164, 1914.

[2] "The Mesozoic Rocks of Applecross, Raasay, and North-East Skye," *Mem. Geol. Surv., Scotland*, 1920.

[3] "The Tertiary Geology of Raasay, Inner Hebrides," *Trans. Roy. Soc. Edin.*, lviii, ii, p. 375, 1935.

Physiographically Raasay is naturally divisible into three parts with E.-W. boundaries, this division being almost wholly dependent upon the nature of the rock formations present. The southernmost region is occupied, in the main, by rocks of Mesozoic and Tertiary age, and is separated from a central Torridonian region by an important fault with a downthrow of about 1000 feet which stretches from Screapadal on the east in a south-westerly direction to north of Holoman. In the north, as in the adjacent island of Rona, the country rocks are Lewisian in age, and are seen to underlie the Torridonian unconformably along a boundary from Brochel to the south of Loch Arnish.

The following rock formations have been observed in the island:

Recent and Pleistocene:
Peat. River Alluvium. Raised Beaches. Drift.

Tertiary Igneous Rocks:
Volcanic Neck Breccias.
Minor Intrusions of Basalt, Dolerite, Tholeiite, Crinanite, Teschenite, Picrite, Dunite, Felsite, Tachylite, and Pitchstone.
Olivine-Dolerite—Crinanite—Teschenite—Picrite Sills.
Granite—Granophyre Sills.
Basalt Lavas.

Unconformability.

Cretaceous:
Upper Cretaceous, (?) Cenomanian. Glauconitic Greensand.

Unconformability.

Cornbrash :

Cornbrash. Calcareous Grit. 15 + feet thick.

Great Oolite :

Great Estuarine Series. Bituminous shales with shelly sandstones and limestones. 250 feet thick.

Inferior Oolite :

Zones from Aalensis to Garantiana. Mainly sandstones, calcareous at base, and resting on shale. Clay at the top. Thickens up to 700 feet.

Stratigraphical Break (Non-Sequence).

Upper Lias :

Zones from Tenuicostatum to Subcarinatum. Oolitic ironstone or limestone resting on shale, and top of Scalpa sandstone. Thickens up to 30 feet.

Middle Lias :

Margaritatus, Lævis, and Spinatum zones. Sandstone—"Scalpa Sandstone," 240 feet thick.

Lower Lias :

Pabba shales. Zones from Raricostatum to Valdani. Shales, about 600 feet thick.

Broadford beds. Lower Lias up to Turneri zone. Chiefly limestones passing up into sandstones. 240 feet thick.

Trias :

Conglomerate with red and green marls at top.

Unconformability.

Pre-Cambrian :

Torridonian. Micaceous shales, sandstones, arkoses, and basal breccias, about 1100 feet.

Unconformability.

Pre-Cambrian :

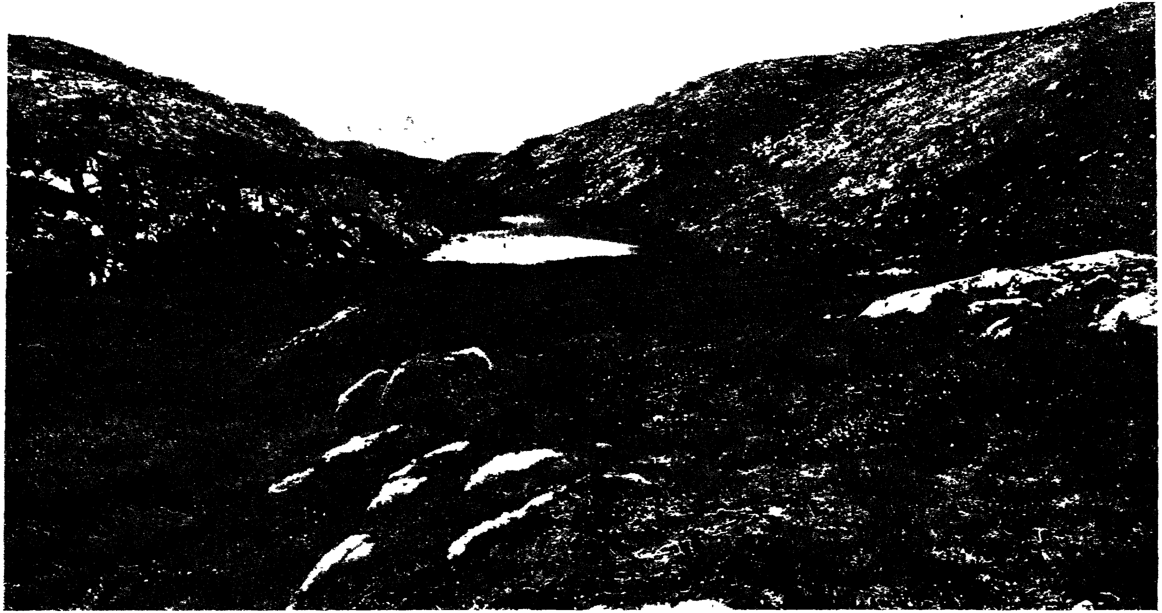
Lewisian Gneiss. Fundamental orthogneisses and intrusive hornblende schists.

PRE-CAMBRIAN ROCKS.

LEWISIAN GNEISS.—The northernmost part of Raasay is similar to the island of South Rona in general geological character, the complex of gneisses giving rise to the barren and desolate scenery so characteristic of parts of the Outer Hebrides. Long ridges of bare rock, with rounded and mammillated surface, reaching in Beinn na-h'-Iolaire a height of 824 feet, alternate with shallow peat-filled valleys commonly oriented in north-north-westerly and north-easterly directions. Steep cliffs of gneiss which commonly border the coast are broken by a series of gullys, inlets, and caves, more conspicuous here than in any other part of the island and due in the main to enlargement of the north-westerly vertical joints. The ten fathom line is in many places immediately inshore.

This Lewisian complex is traversed by a large number of Tertiary dykes up to thirty feet in thickness, mainly of north-north-westerly trend, which commonly weather away more quickly than the gneisses. These dykes are mainly of the composition of crinanite (ophitic analcite-olivine-dolerite).

Petrographically the Lewisian rocks are dominantly hornblende-pyroxene-gneisses, hornblende-biotite-gneisses, and hornblende-epidote-gneisses, of medium or coarse grain, representing a series of metamorphosed plutonic rocks of intermediate composition. Biotite-gneisses, commonly pink in colour, are also abundant, and represent the more acid end of the plutonic series, while basic and ultrabasic inclusions are frequently evident, though less so than in Rona. Many bands of hornblende-schist are locally seen to be clearly intrusive into this fundamental complex, as are also pink and white pegmatite veins, well seen to the south of Loch Arnish. Close to the summit of Beinn na-h'-Iolaire there may also be observed transgressive sill-like masses of a pink biotite-granite, in which foliation is much less marked than in the main complex. These may be akin to the later granite-gneisses of the



Geological Survey Photograph.

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Characteristic Scenery of the Granophyre Area. Bare glaciated surface broken up by frost action: peat lochan lying in ice-eroded hollow.

Two-thirds of a mile north east of Raasay House.

Laxford area, or the granite-gneisses of Beinn Bragor in Lewis.

TORRIDONIAN SANDSTONE.—Unconformably overlying the Lewisian Gneiss landscape between Brochel Castle and the neighbourhood of Loch Arnish is a region of Torridonian sandstone, which extends southwards to the Screapadal fault, and locally reaches over 1,000 feet in altitude. The dominant dip of the sandstone is at a low angle (15°-20°) to the west-south-west, the dip slopes being covered with beds of peat which thin out towards the strike escarpments. In the neighbourhood of Brochel and Inver the monotony of these features is relieved by small stunted woods of birch, oak, willow and rowan.

The thickness of these strata is close on 1,100 feet, and the rocks, which include the Applecross and Diabaig groups, the two lowest divisions of the formation, do not differ appreciably from those of the adjacent mainland. A basement conglomerate is well exposed close to Lochan Uachdair and along the shore of Loch Arnish, while in the neighbourhood of Brochel Castle the succeeding levels of the Diabaig group are seen to be formed of red and grey flaggy sandstones, followed by grey shales. Eilean Fladda is wholly formed of dark flagstones, some of which were at one time used as roofing slates.

The succeeding Applecross group consists of false-bedded red and purple grits and sandstones. This group is also visible in a small outlier at the southern end of Raasay between Rudha na Cloiche and Eirre Point, faulted against Triassic strata which elsewhere in this outcrop overlies the Torridonian with little apparent unconformity.

MESOZOIC AND TERTIARY ROCKS.

The southern division of Raasay is by far the most interesting geologically, for here is found a sequence of Mesozoic deposits unrivalled in Scotland, and a complex of Tertiary igneous rocks of considerable petrographical interest. Much of the high ground of this region, formed by Inferior Oolite sandstones and by a Tertiary granophyre sill, is of barren and glaciated surface; but good pasture for sheep and cattle is found covering other areas of Mesozoic rocks and in particular a district of basaltic sills and lavas from Dùn Cana northward to near the Torridonian boundary. The cultivated land is chiefly either in the Mesozoic areas or in the Recent raised beach deposits along the east coast of the island.

Except where disturbed by local faulting, these Mesozoic and Cainozoic rocks have a pronounced dip to the west or north-west, and accordingly one's expectations of finding the highest land on the east coast are realised. Great precipices rise there abruptly, with almost architectural regularity, to a height of over 1,000 feet, passing upwards to the conspicuous cone-shaped summit of Dùn Cana, 1,456 feet in height, and then descend gradually to reach the western side in a discontinuous series of low cliffs.

The Mesozoic rocks found in the island are but small remnants of once widespread deposits—now found only in scattered outcrops over the Hebridean islands and the adjacent mainland—which owe their preservation to local downfaulting or to protection beneath a resistant cover of lavas poured out during the Tertiary era[1]. As opposed to outcrops in most other islands, however, the deposits of Raasay are relatively unaltered by Tertiary intrusive rocks, and the wealth of palæontological information which they contain makes a visit from any student of Mesozoic stratigraphy well worth while.

TRIAS.—New Red Sandstone rocks occur at two localities in the island, at the southern end of Raasay west of Rudha na Cloiche, and in the neighbourhood of Rudha na Lice. At the former of these localities the Trias is seen to succeed the Torridonian unconformably, while at the latter the unconformable junction is probably at no great depth below sea-level. The beds consist of red and mottled sandstones, sandy marls, grits, cornstones and conglomerates, the pebbles in the conglomerates including quartzite, vein quartz, aplite, and Moine Schist. Pebbles of Durness Limestone, yielding fossil brachiopods and other organisms, have been discovered in the conglomerate at both localities.

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[1] For details of Mesozoic rocks in this and other Scottish areas, see G. W. Lee and J. Pringle, "A Synopsis of the Mesozoic Rocks of Scotland," *Trans. Geol. Soc. Glasgow*, vol. xix, p. 158, 1932.

LOWER LIAS.—The Triassic non-marine strata are succeeded unconformably in the Eirre Burn section by thin beds of shaly limestone which were considered by Woodward to be of Rhætic age. Lee, however, has shown that the evidence for this determination is inconclusive, the rocks grading up insensibly into typical Lower Lias strata with which they are most conveniently grouped, and in the absence of palæontological data the Rhætic must be considered to be absent from Raasay.

It is of interest to note that the Gælic word *leac* (genitive *lice*), a flat stone, which is regarded by Buckman and by Arkell as the most likely source of the word *Lias*, appears in several place names in Raasay—e.g., Rudha na Lice, Beinn na Lice.[1]

The bottom half of the Lower Lias of the Hebrides, well exposed in this island, is a phase of limestones and calcareous sandstones differing markedly from the dark sandy micaceous shales, the Pabba Shales, which form the upper division. In Raasay these calcareous strata, known from their rather similar sequence in Skye as the Broadford Beds, are well seen on the west side of the bay west of Rudha na Lice, where they consist of deposits about 80 feet thick characterised by *Ostrea liassica* Strickland in great abundance, with higher beds at Hallaig, becoming arenaceous towards the top, 140 feet thick, in which the commonest fossil is *Gryphæa arcuata* Lamarck. The palæontology of these beds is fully described in the Geological Survey Memoir. Other small areas of Broadford Beds are seen at South Screapadal, at Fearns, and at the south end of the island, east of the pier.

The succeeding Pabba Shales are much more fully developed than in the small island from which these deposits take their name, where the base of the series is not exposed. In Raasay these beds may be as much as 600 feet thick, and in one section especially they are so well developed and so little altered by later igneous intrusions that this is likely to become a classic area. The lowest beds are best seen in the neighbourhood of Hallaig, but the finest sequence is in the banks of Allt Fearns, a small stream which has its source west of Beinn na Lice, and which reaches the sea between North and South Fearns. Petrographically these beds show little variation, consisting of dark micaceous shales with lenticular bands of fœtid calcareous nodules containing many well-preserved ammonites. All these rocks are highly fossiliferous, and faunal lists extending to over a hundred species of ammonites, lamellibranchs, and belemnites have been recorded by the Geological Survey. The richest fauna is that of the Raricostatum zone, which here occupies about 400 feet of strata, greatly in excess of the thickness of this zone at any other known locality.

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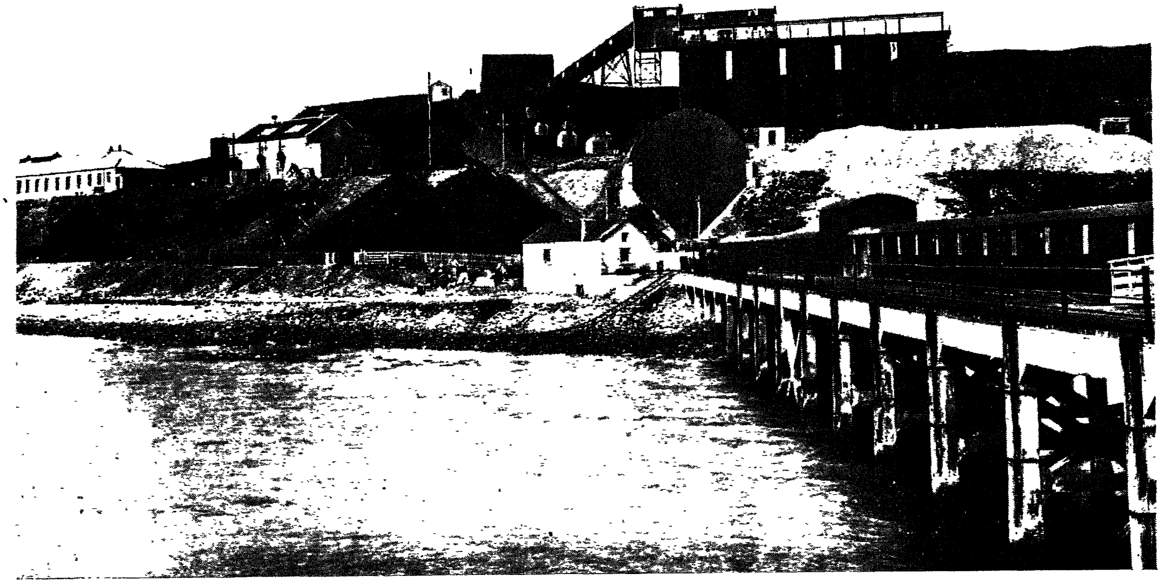
[1] Also seen in southern place-names as Leckhampton, Leckford, Llechryd.

Other exposures of these beds are seen near Suisnish, while the higher zones are observable between Beinn na Lice, and Dùn Cana, and on the shore flats about a mile south of Rudha na Lice.

MIDDLE LIAS.—The Middle Lias of Raasay, as of other outcrops in the Western Islands, is a thick series of massive white and grey sandstones of shallow-water deposition, named by Judd the 'Scalpa Sandstone' from its development in that island. In Raasay this sandstone, which has a thickness of about 240 feet, succeeds the Lower Lias without unconformity, the upper zones of the latter division already showing an incoming of the shallow-water facies.

By reason of its massive nature the Scalpa series has in places given rise to marked series of cliffs, visible between Fearns and Rudha na Lice, and from east of Dùn Cana northwards to Screapadal, where it forms the base of the great precipices, the upper part of which is formed by the Inferior Oolite. Close on a hundred species of fossil mollusca (ammonites, lamellibranchs, and gastropods)



Geological Survey Photograph. *Crown copyright reserved.*

Calcining Works, Raasay Ironstone; Suisnish, Isle of Raasay.

from these beds are recorded in the Survey lists.

Upper Lias.—The great interest of this division in Raasay lies in the occurrence of an important deposit of iron ore discovered in 1893 by H. B. Woodward. The total thickness of Upper Lias is in the neighbourhood of twenty feet, approximately eight feet of this being formed by the ore, which follows on a dark shale facies, sometimes oolitic, from three to nine feet thick.

The ore is markedly oolitic, and is generally rather similar to the well-known Cleveland ore of Yorkshire, which, however, is of Middle Lias age. The Raasay deposit may, therefore, be due to a slow northerly migration of the conditions of iron ore deposition, or to a recurrence of these conditions at a later date.

The common ore, when fresh, is dark green in colour, but on weathering, it turns rusty-brown, due to oxidation of the ferrous iron to a hydrated ferric state. The fresh ooliths are composed of chamosite, a silicate of ferrous iron, alumina, and magnesia, while the matrix is formed of carbonate of lime. Where less than twelve feet of overburden is present, the oxidised ore is not uncommon, much of the lime has been removed by leaching, and the ore has been consequently enriched in iron. Selected specimens yield 30 per cent of iron, but the average rock as mined yielded 23 per cent, with approximately 22 per cent of lime, 0.6 per cent sulphur, and 0.9 per cent phosphorus.

The extent of the ore in the south of the island has been proved by boring to be about ten million tons, while an additional twelve million tons are considered likely to exist in unproved areas.

The Raasay ironstone was worked during the war years from 1916 onwards, but, as the rock is rather low in iron content, production was thereafter discontinued. The high percentage of lime made it suitable for mixing with the siliceous Scottish Carboniferous Clayband ores, and most of the rock was thus smelted in Renfrewshire. Unfortunately, in Home Office (Mines and Quarries) reports[1], details of the production are not given apart from those of the Renfrewshire ores: according to Hatch[2], however, in 1917, 60,000 tons were produced, in 1918, 85,000 tons, but in 1919 the output was apparently less than 4,000 tons[3], and after that year no official return of iron ore production in Inverness-shire is made[4]. Even during the principal period of exploitation of the mine, the production was not more than 0.5 per cent. of the total British Jurassic ores.

Where the overburden was slight, a system of double-trenching was employed, the ore being removed by steam shovels. Over 12,000 tons were obtained by this method in 1916-1918. More commonly however, the rock was obtained from mine workings penetrating over 1,000 feet into the hill-side. From the mine-head it was transported 1¾ miles to the pier, where it was calcined before shipping.

The whole plant is still maintained in tolerably good order, and in a time of national emergency, production could doubtless be started at relatively short notice.

A short distance above the iron ore there follows Inferior Oolite strata apparently without any appreciable break; but detailed investigation has shown that an important non-sequence, representing a period of erosion or non-deposition, occurs towards the top of the Lias, several ammonite zones being represented by the ironstone itself.

INFERIOR OOLITE.—Strata of Inferior Oolite age are present in Raasay to a thickness of 780 feet, the thickest development in the Hebrides. The series forms the main part of the great cliff at Screapadal, towards the base of which are sandy shales (20-70 feet), yielding many fossils. On higher horizons the rocks are more of the nature of sandstones and sandy limestones, containing many large calcareous concretions or 'doggers', good examples of which are more accessible on the western coast at Clachan.

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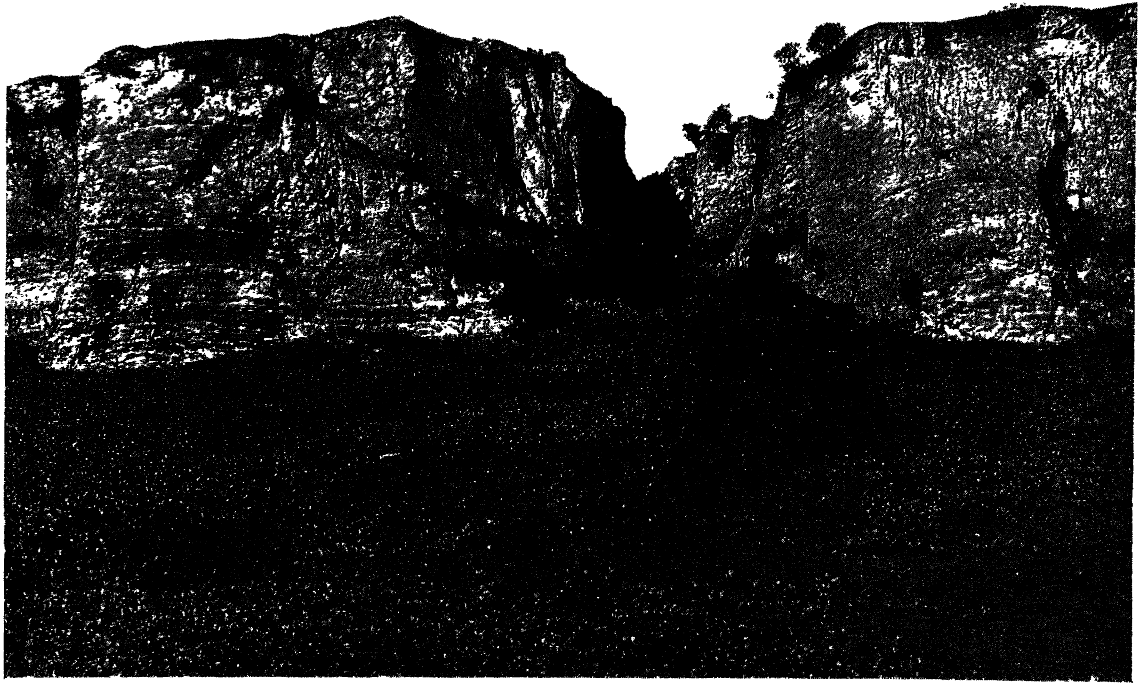
[1] Home Office: Mines and Quarries, General Reports, 1916 onwards.

[2] "The Jurassic Ironstones of the United Kingdom." F. H. Hatch, *Jour. Iron and Steel Inst.*, vol. xcvii, 71-120, 1918.

[3] Imperial Mineral Resources Bureau. Iron Ore: Part I.—The United Kingdom. 1922.

[4] Home Office: Mines and Quarries, General Reports.



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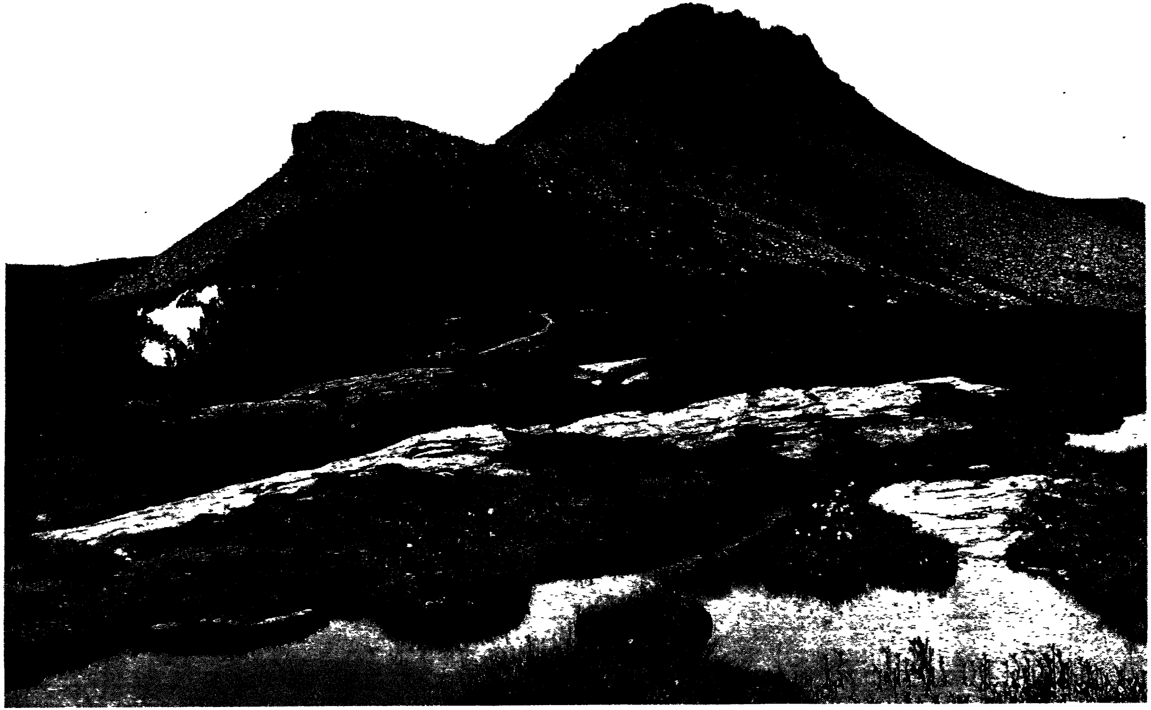
Cliffs of Inferior Oolite; Gualann na Lice, Beinn na Lice, South-east Raasay.



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Tertiary Igneous Rocks capping Inferior Oolite—Dùn Cana and Dùn Cana Beag.
Dùn Cana is formed of basalt lavas; Dùn Cana Beag in front is an intrusive sill.

Organic remains are very scarce in these beds, but in a plastic clay (10 feet) overlying the sandstone facies at Storav's Grave, fossils of the highest zone have been discovered.

GREAT ESTUARINE SERIES.—Following upon the Inferior Oolite strata in Raasay, there is found a series of estuarine shales and limestones, approximately 250 feet thick. This is the stratigraphical equivalent to the marine Bath Oolites of Southern England, with which the contemporary deposits in both eastern and western Scotland are always of estuarine character. From their widespread occurrence in northern Skye, these beds were named the 'Loch Staffin Beds' by Murchison, while Judd has subsequently named the group the 'Great Estuarine Series.'

In Raasay the series occupies a rectangular area from Dùn Cana northwards to the Mesozoic boundary fault, the rocks being overlain in places by basalt lavas and penetrated by basic sills. The lowest bed exposed is an oil-shale eight to ten feet thick, which locally passes into an impure coal. The weathered shale has yielded approximately twelve gallons of crude oil to the ton. The upper beds, 240 feet thick, are sandstones and limestones with *Cyrena*, *Viviparus*, and other estuarine fossils, capped by rocks, seldom found *in situ*, bearing *Ostrea hebridica* Forbes.

CORNBRASH.—A small deposit of early Cornbrash age, gritty white limestone 15 feet thick, succeeds the Great Estuarine Series about a mile north-east of Storav's Grave.

CENOMANIAN ?—Rocks of Jurassic age newer than the Cornbrash have not been discovered in Raasay, and the extensive Cretaceous deposits which once covered this area have been almost entirely removed by denudation. The only Cretaceous rock here seen is an unfossiliferous greensand found on the track leading up Dùn Cana. This, from analogy with similar deposits elsewhere, is referred to Cenomanian age.

TERTIARY IGNEOUS ROCKS.—The Tertiary igneous geology of Raasay is varied and complicated, granophyre, flows of basaltic lava and basic sills covering considerable areas. The granophyre occurs as a sill up to 150 feet thick, which transgresses rapidly from lower to higher horizons, and covers an area of five square miles in the south of the island. The basalt lavas, which form the summit of Dùn Cana and other hills in the Meall Damh area, are in the neighbourhood of 300 feet thick, as opposed to over 2,000 feet in the neighbouring island of Skye. A measure of the great amount of denudation that has taken place since the lavas were poured forth in Eocene times is thereby apparent, while in the north of the island the basalts, together with the underlying Mesozoic rocks and the Torridonian sandstone, have been cleared away right down to the Lewisian floor.

The basic sills of Raasay, found intruding the Mesozoic sediments and the lavas, have consolidated under a cover of varying thickness. Many can be seen in the neighbourhood of Meall Damh, but the largest intrusion, over 300 feet thick, is seen on the west coast between Churchton Bay and Ósgaig. These rocks include a great many petrographic types, the mineralogy of which is dealt with elsewhere[1]. They show close affinities to the sills of northern Skye and the Shiant Isles.

The Tertiary dykes range from types as ultrabasic as dunite to others as acid as pitchstone, but the majority belong to an analcite-olivine-dolerite suite, several representatives being comparatively rich in olivine: probably both regional dykes of the Skye swarm and dyke-fissures which have fed the lava flows are present. The thickest intrusion is a 100-feet dyke on the east coast north of Fearns, but the average diameter is about six feet.

In the neighbourhood of Brochel there are three volcanic necks filled with a breccia of Torridonian sandstone in a calcareous matrix. On one of these is situated the picturesque ruin of Brochel Castle. There is an entire absence of associated igneous rocks, and these masses are regarded by the writer as relics of geysers, hot springs, or similar decadent volcanic stages belonging to late Tertiary times.

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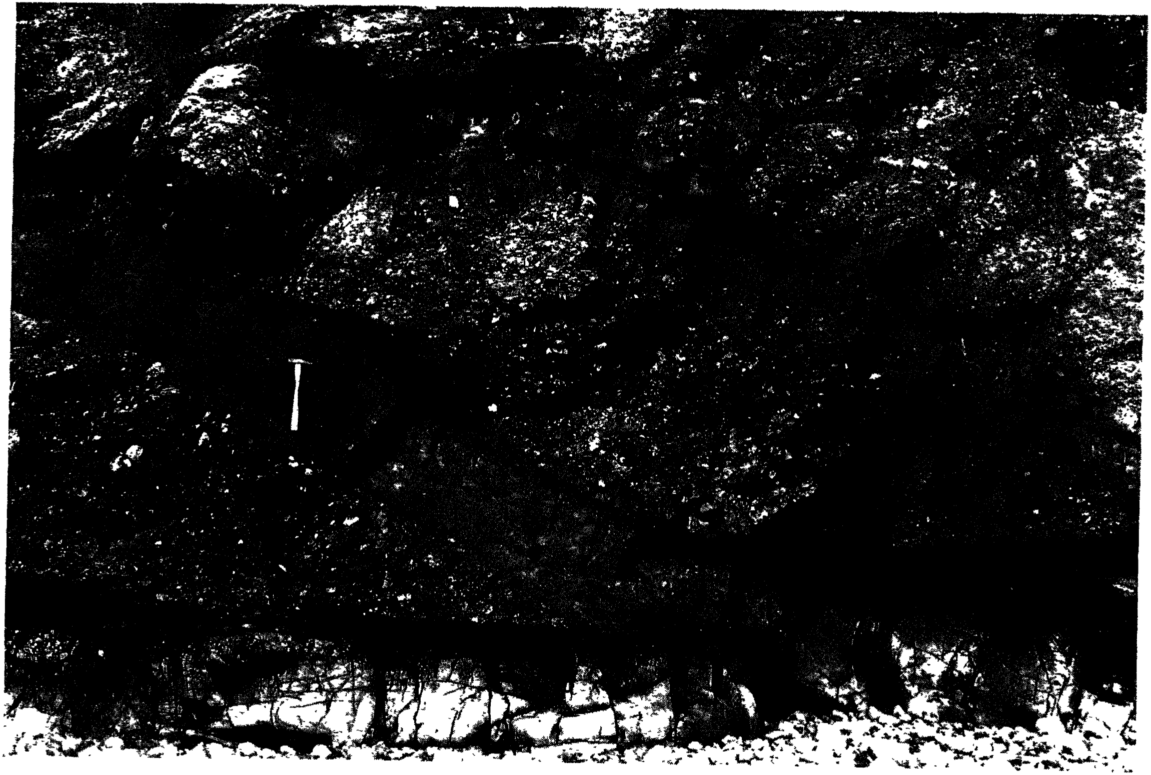
[1] C. F. Davidson, *op. cit.*



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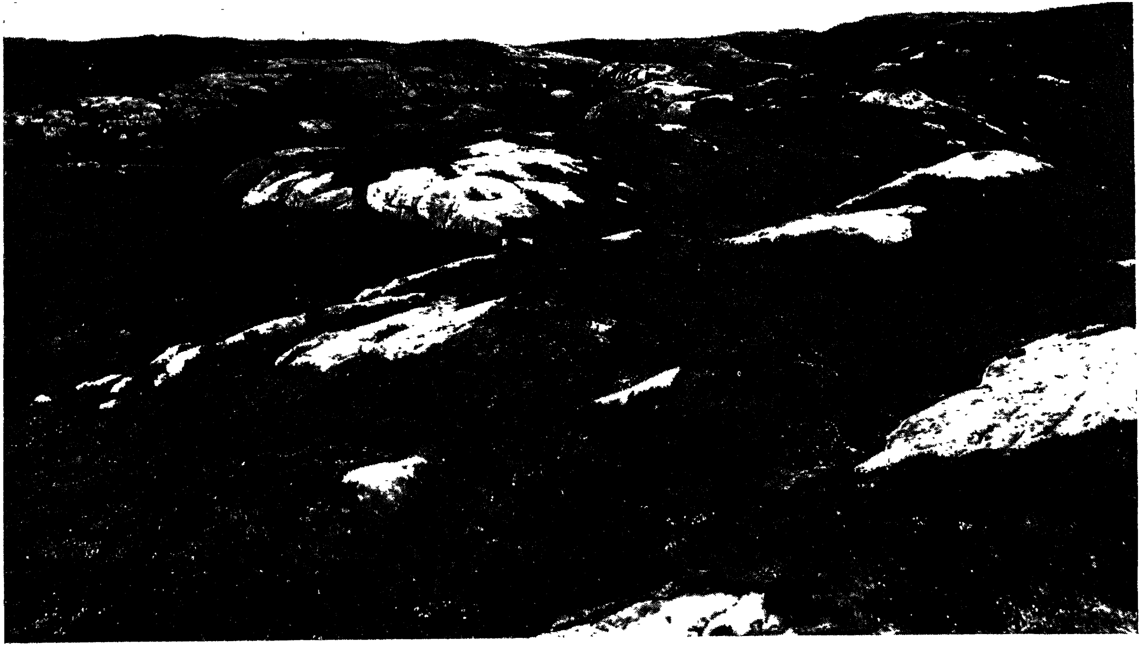
Thin Tertiary Sills cutting Triassic Conglomerate; Rudha na Lice, Isle of Raasay.



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Glaciated Surface of Inferior Oolite.
Summit of Beinn na Lice, South-east Raasay.

PLEISTOCENE AND RECENT.

GLACIAL DRIFT.—During the Great Ice Age, Raasay was covered by a *mer-de-glace* which swept over the island from the south-east to the north-west. The barren glaciated surfaces of many of the hills of the island display good glacial striæ, and boulder clay is widely distributed over the lower ground, the finest sections, in which the deposit may reach forty feet in thickness, occurring close to the Fearns burn west of North Fearns, and overlying the low cliffs near Rudha na Cloiche. The largest of the many erratic blocks distributed over the island's surface is the boulder of Torridonian sandstone, approximately 6×6×9 cubic feet, which gives its name to Rudha na Cloiche.

Many of the small lochs found in the high ground of the island are due to glacial erosion, and some, as Loch na Meilich and Loch na Mnà, coincide in orientation with the direction of ice-flow.

Off the north-eastern coast of Raasay there are some exceptional deeps in the Inner Sound descending to 138 fathoms, and, as James Geikie[1] has estimated, even if this part of Scotland were to be lifted out of the sea for 100 fathoms, there would still be numerous lakes between Raasay and the mainland, one at least of which would reach over 200 feet in depth. There can be little doubt that these deeps are submarine rock basins formed by glacial erosion.

Raised Beach and Recent Deposits.—Raised Beach gravels are locally developed in the south of the island, extending up to about sixty feet above sea-level. These deposits are well seen close to Raasay House, and south of the pier at Suisnish, exposures at the latter locality being quarried. No fossils have been obtained from any of these raised beaches.

In the neighbourhood of South Ósgaig, much of the beach sand is remarkable in containing abundant olivine, occasionally ninety per cent. of the sand being formed of this mineral. Locally these deposits, especially where forming storm beaches, have been cemented into sandstones and conglomerates. These to my knowledge, are the only recorded sedimentary rocks in Europe containing abundant olivine.

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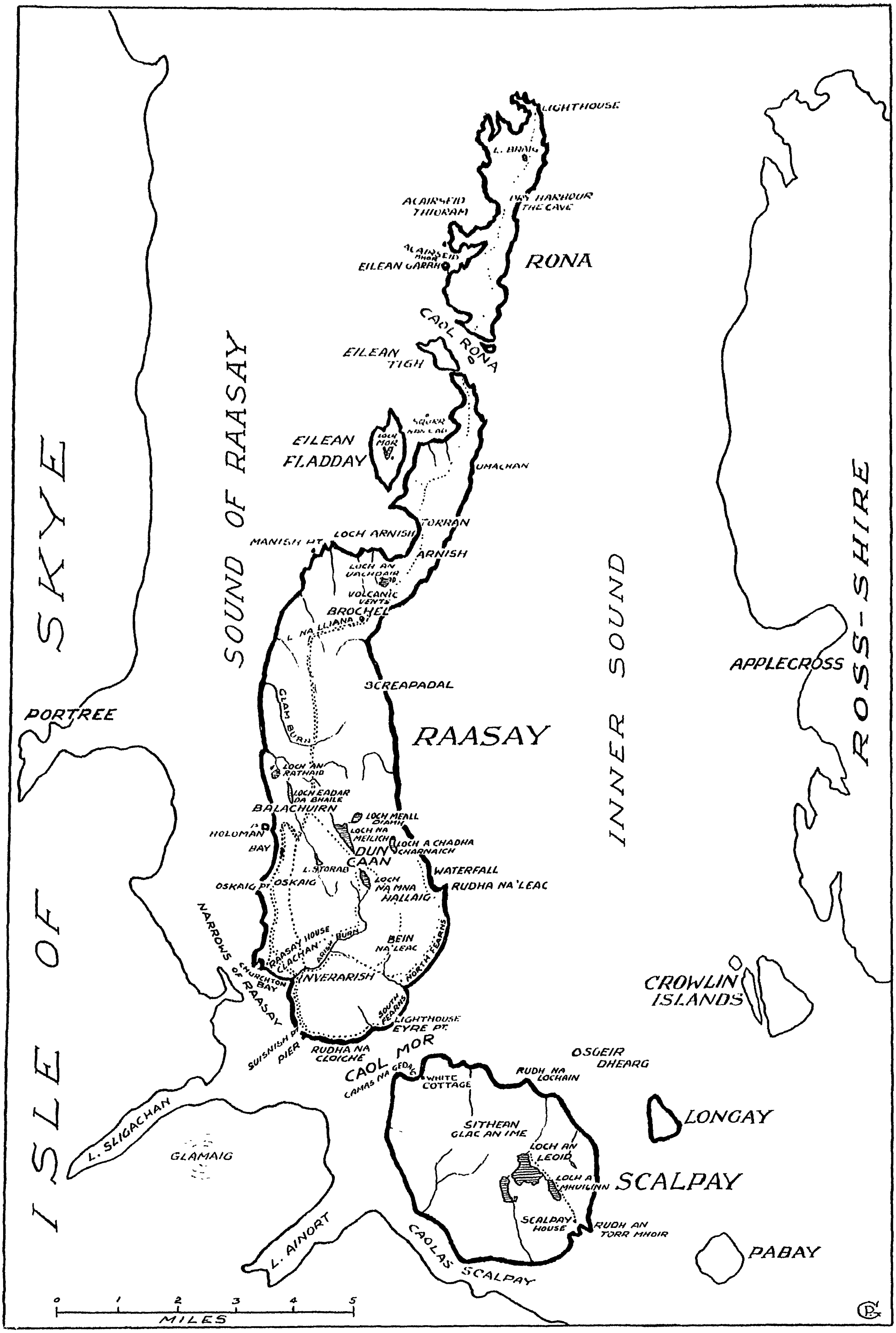
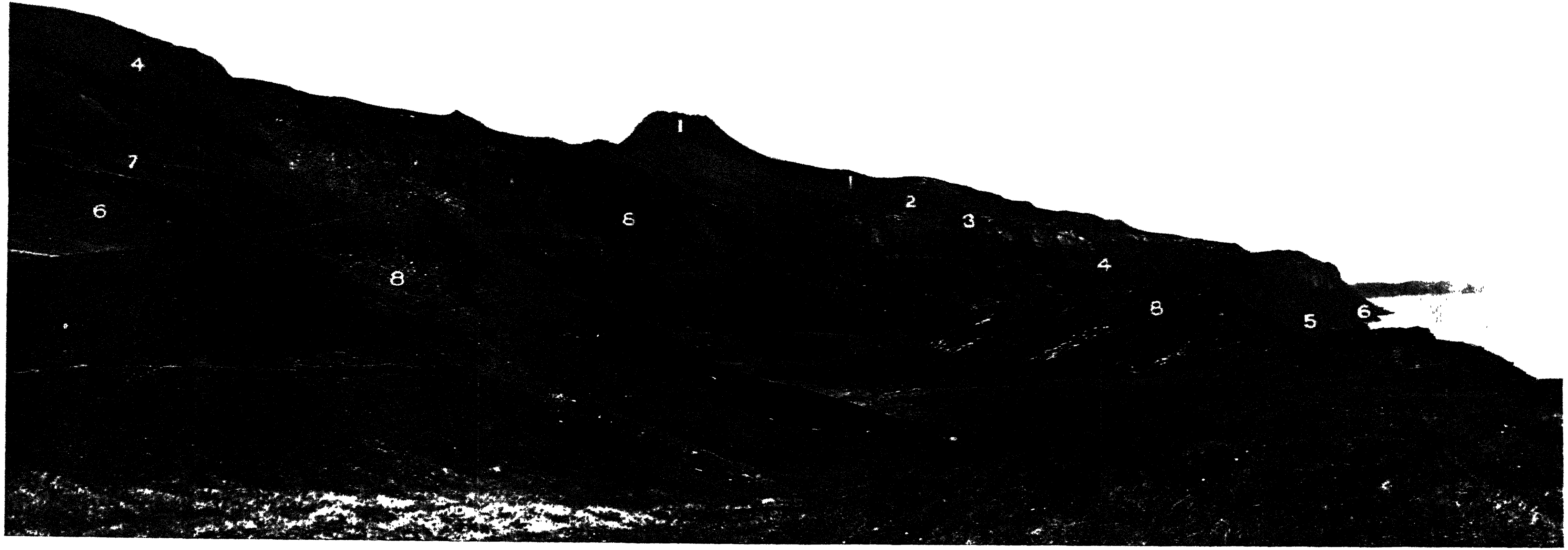
[1] "The Great Ice Age," 3rd edition, 1894, p. 232, pl. viii.

Peat is found over a great part of the island, but its use as a fuel has decreased considerably in recent years, especially in the villages of Clachan and Inverarish. The main cuttings cover the area of Pabba shales west of Beinn na Lice. Extensive deposits are found in the north of the island, and cuttings over eight feet thick are seen near Arnish.

The landslips along the cliffs of the east of the island have been described by many writers, but less well-known is the great net-work of vertical fissures which penetrate the Inferior Oolite strata to the south of Dùn Cana and to the east of the Beinn na Lice fault. These fissures are from one to eight feet broad, descending vertically to great depths. One of the narrower chasms has been sounded to a depth of 150 feet: others may be deeper, and it is to be feared that they will render impossible future mining operations for the underlying iron ore, both south of Dùn Cana and in part of the Beinn na Lice outlier.



MAP OF RAASAY AND OF THE ADJOINING ISLANDS



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General View of East Coast of Raasay, below Dùn Cana. This is the Area in which the Alpine and other Rare Plants grow.

(1) Tertiary basalt lavas and basic sills.
(2) Great Estuarine Series (shales).
(3) Ledge at position of oil shales.
(4) Inferior Oolite sandstone.
(5) Inferior Oolite shales.
(6) Middle Lias sandstone.
(7) Position of Upper Lias ironstone.
(8) Land-slipped material.

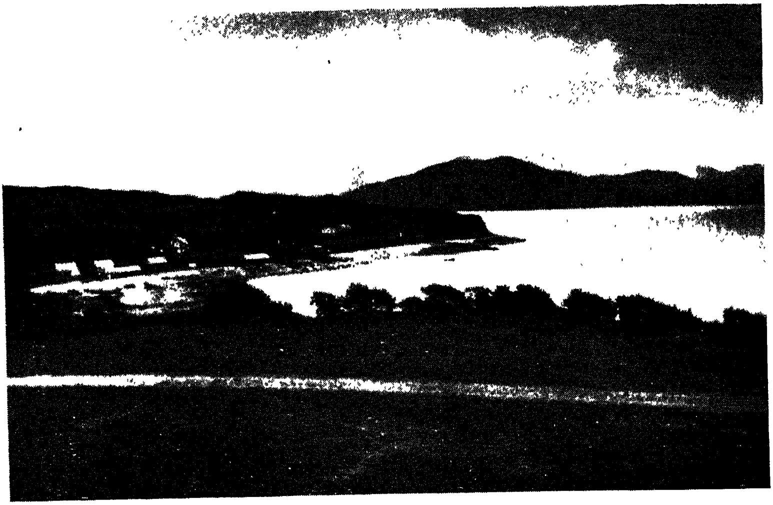


Fig. 1. Suisnish, Raasay.

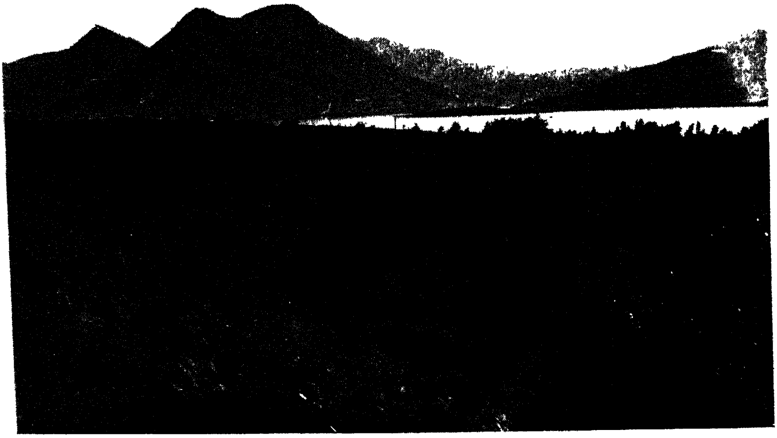


Fig. 2. Along the Arish Burn, Raasay; Glamaig, on Skye, in the background.

THE FLORA OF THE ISLE OF RAASAY AND OF THE ADJOINING ISLANDS OF SOUTH RONA, SCALPAY, FLADDAY AND LONGAY.

By

THE STAFF OF THE DEPARTMENT OF BOTANY,
ARMSTRONG COLLEGE (UNIVERSITY OF DURHAM),
NEWCASTLE UPON TYNE.

INTRODUCTORY.

The following list of the flowering plants and ferns of the islands of Raasay, Scalpay, South Rona, Fladday and Longay, all forming parts of Watsonian Vice-county 104, is the result of somewhat lengthy visits to the islands during the summers of 1934, 1935, and 1936.

In 1934, one of us (J. W. Heslop Harrison) was the guest of an expedition organised by Professor A. D. Peacock of the University College, Dundee. Advantage was taken of the opportunity thus offered to prepare and study large collections of plants from South Rona and Raasay. The results of that work form the basis of the list now published, and the experience thus gained enabled our subsequent efforts to be so directed as to make the best use of our time and opportunities. In 1935. the Departments of Botany of Armstrong College, Newcastle upon Tyne, and of Natural History of the University College, Dundee, collaborated in making an intensive study of the flora and fauna of Raasay. Owing to the personnel of the Armstrong College contingent, the flora was more critically and systematically investigated than had previously been possible. The number of species in the 1934 list was more than doubled, and the additions included many important new records.

During the same season, Longay and Fladday were likewise examined from the botanical standpoint, and it was found possible, by dividing the party into several smaller units, to make a very satisfactory preliminary survey of Scalpay. The expedition of 1936, which was, with one exception, entirely composed of workers from Armstrong College, further increased the list of critical plants, added to our knowledge of their geographical distribution, and enabled us to examine in a more leisurely manner certain productive localities, the possibilties of which had not been entirely exhausted. Our lists were not only extended by the addition of about 50 species, but two Lusitanian plants were discovered, which had not hitherto been reported from Scotland.

Moreover, a more prolonged stay was made on Scalpay, and we were able to study its plants more thoroughly, so that our knowledge of its flora was considerably increased. Advantage was likewise taken of another visit to South Rona to investigate areas not previously examined, and to fill up obvious gaps, recognised from our experience gained on Raasay, as existing in our Rona list. At the same time, in order to obtain some idea of the relations existing between the flora of South Rona and those of the islands lying off its western shores, Eilean Garbh was explored by a small party.

From what has been said above about the composition of the various parties, it will be evident that the labour of collecting and studying the plants fell mainly on the staff of the Department of Botany of Armstrong College. However, so valuable were the services of Mr. R. B. Cooke in that direction that we were compelled to regard him as an honorary member of that staff. So far as the flowering plants, the ferns, and the fern-allies are concerned, the following were responsible for the bulk of the work:—

Mr. A. W. Bartlett, M.A., M.Sc.
Miss K. B. Blackburn, D.Sc.
Miss E. Bolton, M.Sc.
Mr. W. A. Clark, B.Sc., Ph.D.
Mr. R. B. Cooke.
Miss H. Heslop Harrison, M.Sc.
Professor J. W. Heslop Harrison, D.Sc., F.R.S.

Fig. 3. The Party on Skye.

Fig. 4. The Old Mill, Inverarish, Raasay.

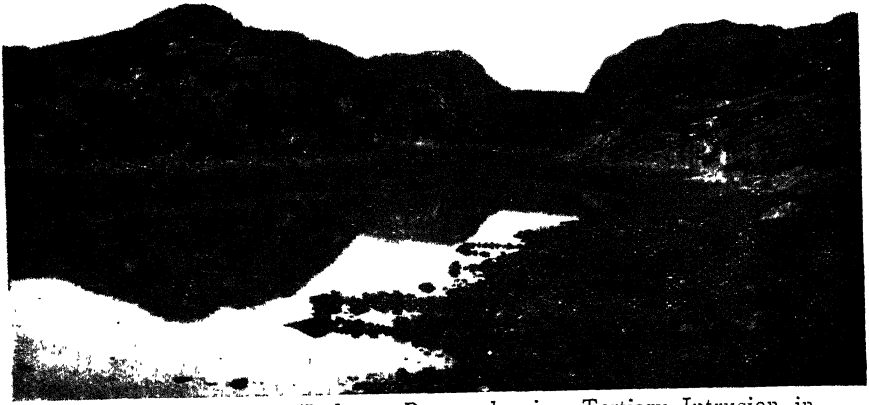


Fig. 5. Part of Dry Harbour, Rona, showing Tertiary Intrusion in Lewisian Gneiss.

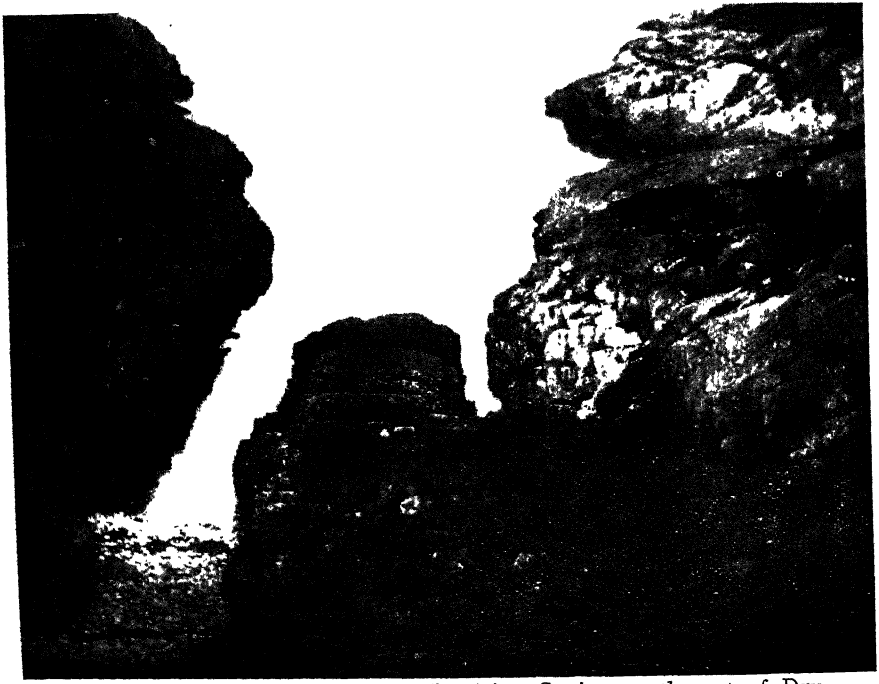
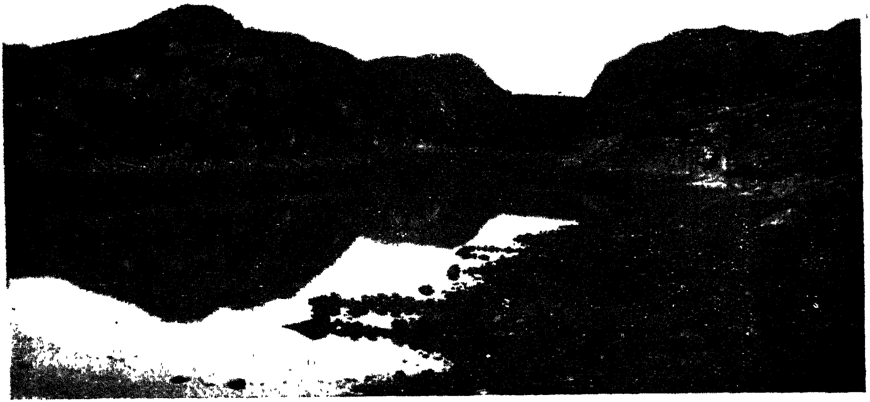


Fig. 6. Tertiary Dyke invading Lewisian Gneiss, north-west of Dry Harbour, Rona.



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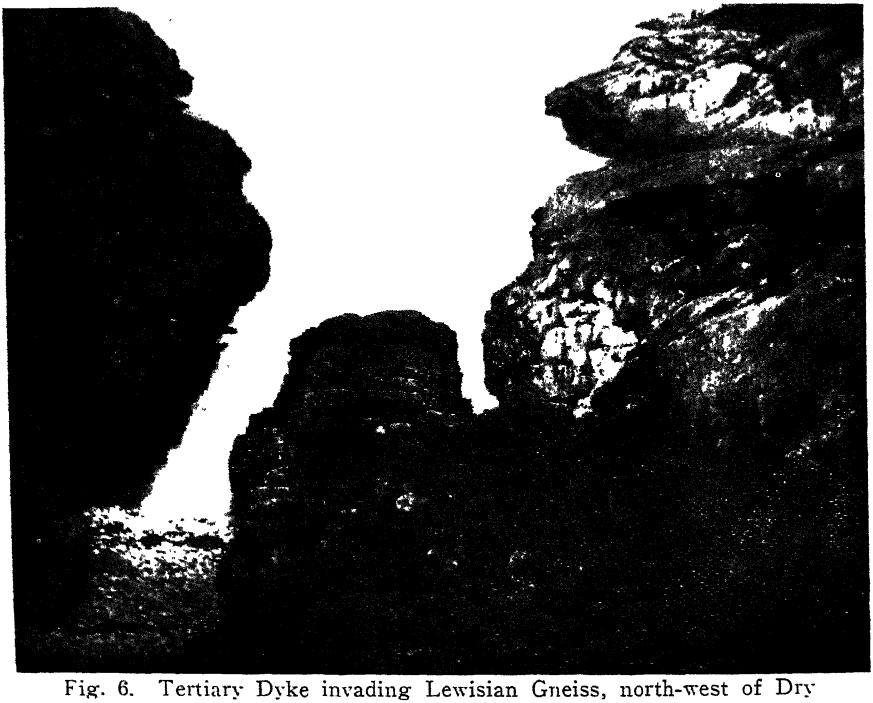

Fig. 6. Tertiary Dyke invading Lewisian Gneiss, north-west of Dry Harbour, Rona.

The following students also rendered very valuable and capable assistance:—

Miss H. B. Bond, B.Sc., Mr. D. Cameron, B.Sc.
Miss M. H. Oates, B.Sc., and Miss B. Todd.

Furthermore, although their efforts were mainly directed towards solving the problems of the numerous lochs, Dr. B. Millard Griffiths and Miss K. M. Chalklin, M. Sc., of the University Science Laboratories, Durham, furnished valuable information with regard to the aquatic plants, which is incorporated here. A tribute, too, must be paid to Mr. P. Gibson for his assistance in pressing and preserving material, and for much valuable help in many other ways.

Of these mentioned above, Mr. A. W. Bartlett paid special attention to the Pteridophyta, Dr. K. B. Blackburn to the Violaceae and Hieracia, Miss H. Heslop Harrison to the Gramineae, Professor J. W. Heslop Harrison to the Rubi and Salices and Miss E. Bolton and Professor J. W. Heslop Harrison to the Roses.

All the islands explored lie to the east of the Isle of Skye, from which they are separated by the Sound of Raasay on the north, and Caolas Scalpay on the south. To the east, across the Inner Sound, is the Applecross district of Ross-shire. The most northerly island, South Rona is, like Raasay, roughly orientated in a north and south direction; it has a length of just under four miles, and a maximim breadth of one and a quarter miles. Geologically speaking it is a rugged mass of Lewisian gneisses, intersected by dykes of rocks of various types. To the south, and divided from it by the turbulent Caol Rona, stretches the Isle of Raasay, with a length of over thirteen miles, and a breadth varying between half a mile near Torran to three miles at Oskaig. Unlike South Rona, which has a more or less uniform structure throughout, Raasay may be considered, on a geological basis, as separable into three distinct regions. The first of these, lying north of the Brochel—Loch Arnish line, completely resembles in structure South Rona, except for the Island of Fladday lying to the west, which is built up of Torridonian sandstones. To the south, and extending in an oblique line from Screapadal on the east to Holoman on the west, is an area occupied by Torridonian sandstones agreeing with those of Fladday, whilst southwards again are masses of rocks of Mesozoic and Tertiary ages. In this region, apart from the bare, barren granophyre sill, occupying the triangular stretch of country between Holoman and Oskaig, and extending almost to Dun Caan (1456 feet), are included enormous outcrops of Mesozoic rocks of varied and interesting types. This area, especially on the eastern fringe, consists of magnificent rugged precipices, and wherever the limestone appears, is richest from the floristic standpoint, and yielded our best records. Further to the south, across Caol Mohr, Scalpay looms up as a grey mass, of which the length and breadth are both approximately four miles. This island is far more uniform from the geological standpoint than Raasay, for the bulk of it is composed of Torridonian sandstones with occasional bands of limestone appearing at intervals. Just where our camp was pitched, there was an interesting variation in the form of a patch of Triassic conglomerate, one hundred feet thick, including Torridonian sandstones, limestones, etc. To the west and south, respectively, a granophyre sill, and basalts of limited extent appear, whilst on the south east, and separated from the basalt by a wedge of Torridonian, rocks of Jurassic age, mostly Scalpay and Pabbay shales and sandstones, with some limestone, are encountered. This latter tract was of special interest botanically. Lastly, Longay, lying a mile to the east of Scalpay, is almost entirely composed of red Torridonian sandstones, with the exception of some igneous intrusions. The climate of the islands is moist and very equable. The rainfall, nevertheless, is much less than one would expect from their geographical position, and from a consideration of the rainfall of Skye, of other western islands, and of Western Ross-shire. The prevailing winds blow from the west and south west, and a glance at the map will

Fig. 7. The Landing on Scalpay; Raasay in the background.

Fig. 8. The "Camp" on Scalpay with the Gorge of Allt Camas na Geadaig in the foreground.

show that, under ordinary circumstances, they will be deprived of much of their moisture by the mountains of Skye before reaching South Rona, Raasay, and Scalpay. In fact, the average annual rainfall, as registered at South Rona lighthouse, is just under 32 inches, and that of Raasay is decidedly lower than this. In all these islands the rain mostly falls in the months of October, November, December, and January. Snow is of rare occurrence, and seldom remains any length of time, whilst frosts are almost absent. The driest periods of the year occur in spring and early summer, so that there is scope for a reasonable amount of sunshine. The mildness of the climate is reflected in the luxuriance of the vegetation, which, except for the heather—mat grass moorland, suggests climatic conditions of stations lying far to the south. In support of this statement, one may mention the hedges of Fuchsia and Escallonia and the well grown Eucalyptus trees on Raasay, and the ripening of peaches and the successful growth of many tender plants out of doors on Scalpay.

Taking cognisance of all these facts, therefore, one is not surprised at encountering plants of southern and south-western predilections, which have not hitherto been reported from the more exposed islands to the west. The same explanation, too, may be given for our being able to add *Juncus pygmaeus* and *J. capitatus* to the flora of Scotland, and *Cicendia pusilla* to the British list.

Including species, segregates in critical genera, and hybrids, the total number of forms listed is 603. This figure is, of course, unexpectedly high when due consideration is given to the comparatively small area investigated, and to its geographical position. It should, however, be pointed out that 49 forms belonging to the genus Rosa, 12 to Rubus, 14 to Hieracium, and varying, but generally smaller, numbers appertaining to other similar genera, find places on the list.

If the major genera in the critical groups, and naturalised species are ignored,* then exactly sixty new county records are presented; in addition, fifty four plants, recorded here, do not appear in Druce's Flora of West Ross. Much the same sets of species occur in both of the categories, but *Silene Cucubalus*, *Eupatorium cannabinum, Scutellaria minor, Epipactis atropurpurea,* and *Carex vulpina,* present in V.C. 104, seem noteworthy absentees from West Ross. On the other hand, *Vicia angustifolia, Geum urbanum, Adoxa Moschatellina, Myriophyllum spicatum, Myosotis palustris, Cladium Mariscus, Luzula pilosa, Sparganium simplex,* and *Carex distans,* previously signalled from West Ross by Druce, are important plants now recorded, for the first time, from V.C. 104.

Within the islands studied, several peculiarities in distribution seem worthy of comment. Eight plants (including 2 new county records), *Ranunculus hederaceus, Lythrum Salicaria, Erythraea Centaurium, Carduus nutans, Salicornia europaea, Atriplex glabriuscula, Potomogeton natans* and *Cladium Mariscus* are restricted to Rona; fourteen (with nine new county records), *Ranunculus scoticus, Nuphar pumila, Subularia aquatica, Prunus Padus, P. avium, Rosa spinosissima, Viola segetalis, Adoxa Moschatellina, Viburnum Opulus, Myriophyllum spicatum, Paris quadrifolia, Glyceria declinata, Hymenophyllum tunbridgense,* and *Lycopodium annotinum* to Scalpay, whilst no fewer than 104 were found on Raasay alone—a list too long to quote at full length.

In accounting for such a great preponderance of plants limited in their distribution to Raasay, it is, no doubt, tempting to assert that that island was much more intensively worked than the remainder; nevertheless, we do not think that the difference so produced is significant. Thus we must look elsewhere for an explanation of the position. In the first place, cultivation affects a much greater area on Raasay than on the other islands, and this accounts for about a dozen weeds of arable land found there, and not elsewhere. Similarly, the influence of Raasay House, and its grounds, may be held responsible for much the same number. Of the remainder, many are widespread, and almost certainly the greater variety of habitat, both geologically and biologically speaking, offered by Raasay, and its superior size, explains their presence.

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*This is rendered necessary by the uncertainty attending the application of the names employed by Druce, and others, in dealing with such groups.

However, by far the most interesting and important groups are the Alpine and other plants confined to habitats on the cliffs and slopes lying along the east coast between Screapadal and Fearns. Undeniably, many of the species so restricted are genuine Alpines or calciphiles like *Dryas octopetala*, *Silene acaulis*, and *Epipactis atropurpurea*, but still quite a large assemblage, exemplified by *Geum urbanum*, *Petasites ovatus*, *Nasturtium officinale*, *Geranium lucidum*, *Anthyllis Vulneraria*, *Listera ovata*, *Carex vulpina*, *Phalaris arundinacea*, *Calamagrostis epigeios*, and *Lastrea aemula*, belong to neither of the sections just named. Their occurrence depends upon geological factors, too complicated to be detailed here, and consequently reserved for further consideration and treatment.

In the compilation of this list it should be noted that, as far as possible, the nomenclature of the eleventh edition of the London Catalogue has been followed.

THE LIST OF PLANTS.

RANUNCULACEÆ.

THALICTRUM

T. **alpinum** L. Alpine Meadow Rue.
In Raasay, sparingly on the cliff ledges from Screapadal southwards, but very plentiful as a kind of fringe to Loch na Meilich; much rarer on Scalpay, Sithean Glac an Ime at 900 feet.

ANEMONE.

A. **nemorosa** L. Wood Anemone.
On Raasay, Rona, and Scalpay; locally abundant on open moorlands, grassy slopes, and ledges.

RANUNCULUS

R. **hederaceus** L. Ivy-leaved Crowfoot.
On Rona only; damp ground near the old village of Dry Harbour.

R. **Flammula** L. Lesser Spearwort.
On Raasay, Scalpay, Rona, Fladday, and Longay, common in wet places; found at 1400 feet on Dun Caan.

R. **scoticus** E.S. Marshall.
On Scalpay, in shallow streams on the northern slopes.

R. **reptans** L.
On the margin of a small loch west of Oskaig, Raasay; new to V.C. 104.

R. **auricomus** L. Goldilocks.
Very rare on the rocks just above the waterfall, Hallaig, Raasay; in the ravine of Allt Camas na Geadaig, Scalpay, and more plentiful amongst rocks in east Rona, opposite Dry Harbour. A new county record.

*R. **acris** L. Buttercup.
Common and general on all the islands; var. *pumilus* Wahlbg. on Dun Caan, Raasay, and Ben Loch a Mhuilinn, Scalpay.

R. **repens** L. Creeping Buttercup.
Scattered over all the islands, including Longay and Fladday, but not at all common.

R. **bulbosus** L. Bulbous Crowfoot.
Only once, in ground previously cultivated, Inverarish, Raasay; probably not native.

R. **Ficaria** L. Pilewort.
Common and generally distributed in suitable places on Raasay and Scalpay.

CALTHA.

C. **palustris** L. Marsh Marigold.
Plentiful in wet places, Raasay, Scalpay, Rona, and Fladday.

C. **radicans** Forst.
First detected on the margin of marshy ground near the sea, Fearns, Raasay; later found to be abundant on Rona.

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* The asterisk prefixed to the name of a species indicates that the plant is found on Eilean Garbh, a rocky islet lying off the west coast of South Rona.

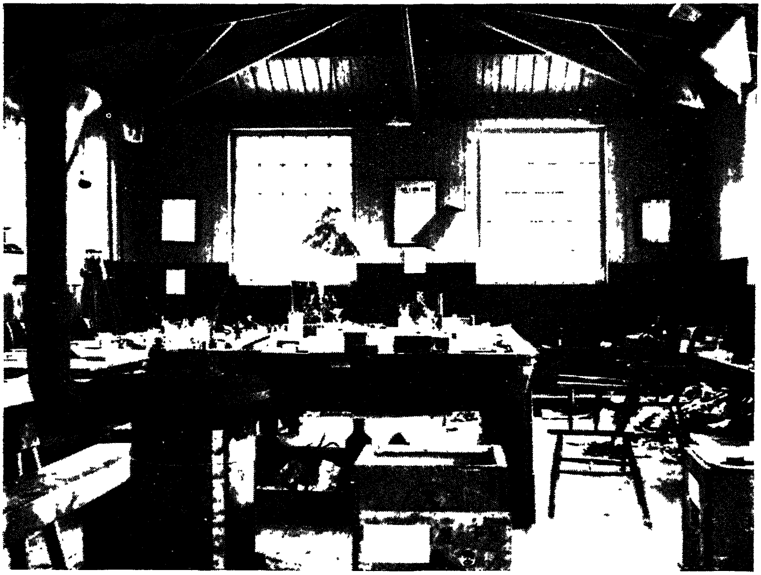

Fig. 9. The Laboratory on Raasay.

Fig. 10. Along the Storab Burn, the only Raasay locality for *Juniperus communis*.

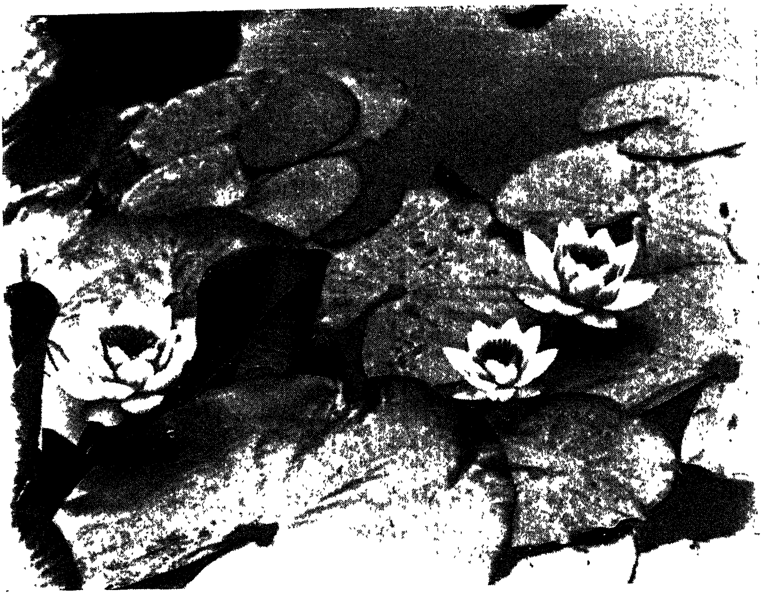

Fig. 11. White Waterlilies; abundant in all the Larger Lochs.

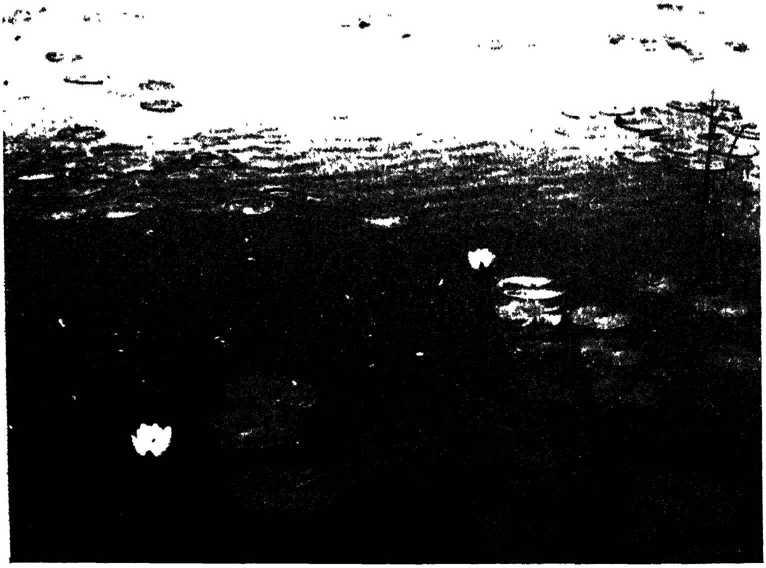

Fig. 12. Waterlilies and Lobelia in the Smaller Lochs along the Inverarish-Brochel Road.

AQUILEGIA.

A. vulgaris L. Columbine.
A garden escape, Inverarish, Raasay.

NYMPHÆACEÆ

NUPHAR

N. pumila DC. Small Waterlily.
Not common in Loch a Mhuilinn on Scalpay; a new county record.

NYMPHÆA.

N. alba L White Waterlily.
In most of the lochs on Raasay, Rona, Fladday, and Scalpay to about 800ft.; abundant.

N. occidentalis Moss.
In more lowlying lochs on Raasay.

FUMARIACEÆ.

CORYDALIS.

C. claviculata DC. Climbing Fumitory.
Rare and local, always on sandstones, or shales; Screapadal and Point of Eyre, Raasay; Rudh'an Torr Mhoir, Scalpay.

CRUCIFERÆ.

NASTURTIUM.

N. officinale R. Br. Water Cress.
Rare, only in small streams at sea level, Rudha na Leac, and Fearns, Raasay.

ARABIS.

A. petræa Lam.
On the cliffs east of Dun Caan.

A. hirsuta Scop. Hairy Tower Cress.
East coast of Raasay, Screapadal to Rudha na Leac; also cliffs on Scalpay.

CARDAMINE.

C. pratensis L. Cuckoo Flower.
Common in wet places on Raasay, Scalpay, and Rona; both the white flowered and the lilac flowered forms occur.

C. hirsuta L. Hairy Bitter Cress.
Not rare, but chiefly a shingle plant in many places; Raasay, Scalpay, and Fladday.

C. flexuosa With.
Of free occurrence along shady ravine sides, Raasay, Scalpay, Longay, and Rona.

DRABA.

D. incana L.
On limestone along the eastern coast cliffs of Raasay; fine and very variable.

EROPHILA.

E. verna E. Meyer. Vernal Whitlow Grass.
On ledges west of Storab's Grave, and near the Mermaids; rare. Apparently a new county record.

COCHLEARIA.

C. officinalis L. Scurvy Grass.
On the shores of all the islands.

***C. danica** L.
West coast of Raasay, also on Rona, and Scalpay.

C. groenlandica L.
Found amongst shingle; southern and western Raasay.

SISYMBRIUM.

S. Thalianum Gay. Thale Cress.
Dry slopes near Raasay House, and on a hill north of Dun Caan; not common.

SUBULARIA.

S. aquatica L. Awlwort.
At the north end of Loch an Leoid, Scalpay.

BRASSICA.

B. arvensis L. Charlock.
On cultivated ground, Raasay, but not plentiful.

CAPSELLA.

C. Bursa pastoris Medik. Shepherd's Purse.
Common enough on the larger islands; in all suitable places.

LEPIDIUM.

L. Smithii Hook.
Near Inverarish, Raasay; rare.

VIOLACEÆ.

VIOLA.

V. palustris L. Marsh Violet.
Common in boggy ground; all islands examined.

V. silvestris Lam. Dog Violet.
Grassy places on Raasay; apparently a new county record.

***V. Riviniana** Reich. Violet.
Common in most places on all the islands, but not on Dun Caan.

V. canina L. Dog Violet.
Many stations; Balachuirn, Holoman, Oskaig, and Inverarish, Raasay.

V. Lloydii Jord. 'Pansy.
On a curious ridge in a field near Oskaig; plentiful, also on Scalpay.

V. lepida Jord. Pansy.
In dry fields; also collected in the Oskaig area.

V. arvatica Jord. Pansy.
On Fladday only; not typical and possibly of hybrid origin.

V. segetalis Jord. Field Pansy.
In fields on Scalpay only.

POLYGALACEÆ.

POLYGALA.

P. vulgaris L. Milkwort.
Common on most of the moors of the various islands except Rona.

P. dubia Bellynck.
Sparingly on the north of Scalpay, and in S. W. Raasay.

***P. serpyllacea** Weihe.
On all the islands save Longay.

CARYOPHYLLACEÆ.

SILENE.

S. Cucubalus Wibel. Bladder Campion.
Quite rare; Clachan area, Raasay only.

S. maritima With. Sea Campion.
Of limited distribution; south of Oskaig Point, abundant in the shingle; on the cliffs near Rudha na Leac at elevations between 300 and 650 ft., Raasay only.

S. acaulis L. Moss Campion.
Very fine on the sea cliffs between South Screapadal and Rudha na Leac, most plentiful near Hallaig, and extending inland slightly at that station. White flowered forms, as well as those with various shades of pink and red, occur. Raasay only.

LYCHNIS.

L. dioica Mill. Red Campion.
Quite rare, rocky woods on, or near, the cliffs at Screapadal and Hallaig, on the shingle near N. Fearns, Raasay. The flower colour in all cases is of a deep crimson, and the plants at Screapadal approach var. *zetlandicum* Compton. On Scalpay, only on the Pabbay shales, flowers large, and light pink in some examples, in others, normal.

L. Flos-cuculi L. Ragged Robin.
Common in marshy places on all the islands except Longay.

CERASTIUM.

C. viscosum L. Mouse-ear Chickweed.
Common enough, Raasay, and Scalpay.

***C. vulgatum** L. Mouse-ear Chickweed.
Common on all the islands.

STELLARIA.

S. media Vill. Chickweed.
Common everywhere on cultivated soil, but apparently not collected on Fladday.

S. Holostea L. Stitchwort.
Quite local on Raasay and Scalpay, only to the west of the first named island, and to the south of Scalpay.

S. graminea L. Heath Stitchwort.
Sparingly on Scalpay, Raasay, and Rona.

S. uliginosa Murray. Bog Stitchwort.
On the margins of most of the smaller burns, but not seen on Longay or Fladday.

ARENARIA.

A. trinervia L. Three-nerved Sandwort.
In the woods around Raasay House, and not at all plentiful; a new county record.

A. balearica L.
Thoroughly naturalised on the walls near Raasay House.

A. peploides L. Sea Purslane.
Very unexpectedly rare; on Raasay near Oskaig, on Rona near Dry Harbour and Big Harbour, on Scalpay on the bay west of Rudha Doire na Bo Ceanain in the north, and near the jetty in the south.

SAGINA.

S. maritima G. Don.
Uncommon, Oskaig Point, Raasay, and Dry Harbour, Rona.

***S. procumbens** L. Pearlwort.
Common in most waste places, on all the islands excluding Fladday.

S. subulata Presl.
On Meall Daimh only, Raasay; west of Scalpay.

SPERGULA.

S. sativa Bœnn. Corn Spurrey.
Extremely abundant, wherever cultivation is attempted, on Raasay, Scalpay, and Fladday.

SPERGULARIA.

S. salina Presl. Sea Spurrey.
At very scattered points on the Raasay coast, Oskaig and Screapadal; Big and Dry Harbours, Rona; near Rudh'an Lochain, Scalpay.

S. marginata Kittel. Sea Spurrey.
Only on the south shores of Scalpay in the saltmarsh.

PORTULACEÆ.

CLAYTONIA.

C. alsinoides Sims.
Completely naturalised, and abundant in the woods around Raasay House.

MONTIA.

M. fontana L. Water Blinks.
The var. *lamprosperma* occurs locally in the west of Raasay and Scalpay.

HYPERICACEÆ.

HYPERICUM.

H. Androsæmum L. Tutsan.
Very curiously distributed on Torridonian sandstones and conglomerates; Inverarish, South Fearns, cliff bases, etc. near the Point of Eyre Lighthouse, Raasay, Fladday, south end of Longay, and on the Triassic on N. Scalpay.

H. dubium Leers. St. John's Wort.
In Raasay House grounds, possibly introduced, but known to natives of Raasay for many years; a new county record.

H. tetrapterum Fr. St. John's Wort.
Very rare; in northern Raasay, near Arnish only.

H. humifusum L. Creeping St. John's Wort.
Quite sparingly on banks near Balachuirn, Raasay.

***H. pulchrum** L. Beautiful St. John's Wort.
Very common on the moorlands, banksides, path sides, etc., on all the islands; var. *procumbens* Rostrup on banks along the Storab Burn after it leaves Loch Eadar da Bhaile.

TILIACEÆ.

TILIA.

T. vulgaris Hayne. Lime.
Planted at Big Harbour, Rona and likewise in Raasay House grounds.

LINACEÆ.

LINUM.

L. catharticum L. Purging Flax.
Very common on dry banks, Raasay, Rona, and Scalpay.

GERANIACEÆ.

GERANIUM.

G. dissectum L. Cut-leaved Crane's-bill.
On cultivated ground, Inverarish and S. Fearns, Raasay.

***G. molle** L. Dove's Foot Crane's-bill.
Found near, and on, cultivated ground on Raasay.

G. lucidum L. Shining Crane's-bill.
On the cliffs near the shore, Hallaig, Raasay only.

G. Robertianum L. Herb Robert.
Common on Raasay and Scalpay; appearing on the former island, in enormous masses, as a shingle plant between South Fearns and Rudha na Cloiche.

OXALIS.

***O. acetosella** L. Wood Sorrel.
All islands except Fladday, in woods and shady places; ascends 1300 feet on Dun Caan.

AQUIFOLIACEÆ.

ILEX.

I. Aquifolium L. Holly.
Evidently once widespread, but now restricted to sea-cliffs or other cliffs, like those bounding one of the smaller lochs on Rona. On Longay, several trees are spreadeagled in a very curious fashion along the cliffs on the west coast although well grown examples are to be found on rocks inland; on all the islands.

ACERACEÆ.

ACER.

A. Pseudo-platanus L. Sycamore.
Planted on Raasay, Rona, and S. Scalpay; apparently wind dispersed to N. Scalpay.

LEGUMINOSÆ.

ULEX.

U. europæus L. Whin, Furze, Gorse.
On Raasay, near Raasay House, and abundantly on the old road between Fearns and Hallaig, also on the edge of the Allt Camas na Geadaig, Scalpay; may have been introduced, but certainly looks native in E. Raasay, and on Scalpay.

CYTISUS.

C. scoparius L. Broom.
One plant amongst heather on the moorland road above Holoman, and others nearer Inverarish; is probably native, as broom insects, like *Depressaria assimilella*, occur on it.

MEDICAGO.

M. lupulina L. Non such.
Rare as a weed of cultivation near Churchtown Bay.

TRIFOLIUM.

T. pratense L. Red Clover.
Grassy places; everywhere except on Longay and similar moorland areas.

T. hybridum L. Alsike Clover.
In fields and introduced; Raasay, near Inverarish only.

***T. repens** L. Dutch Clover.
Not at all rare, everywhere on the lower lying areas of the islands, and even on the "table land" of Longay.

T. dubium Sibth. Small Hop Trefoil.
In the vicinity of Raasay House and Brochel; Raasay.

ANTHYLLIS.

A. Vulneraria L. Kidney Vetch.
On the east coast of Raasay as a cliff plant only, and then rare and local; on the conglomerate of volcanic vents at Brochel, and on the middle zones of the cliffs above the old path near Rudha na Leac.

LOTUS.

***L. corniculatus** L. Bird's Foot Trefoil.
Common everywhere, and ascending to 1400 feet on Dun Caan and 900 feet on Beinn Loch a Mhuilinn, Scalpay. Large flowered varieties occur, whilst var. *incanus* Gray, is to be found near Suisnish Point.

L. uliginosus L.
Not very common on Raasay and Rona, in damp places.

VICIA.

V. hirsuta Gray. Hairy Tare.
Sparingly in the Inverarish area.

V. Cracca L. Blue Vetch.
May be found on all the islands other than Longay, but on Raasay chiefly in fields. The colour of the flowers in Raasay examples is a very different blue from that of typical Northumberland and Durham forms.

V. sepium L. Bush Vetch.
Thinly distributed on Raasay and Scalpay.

V. sativa L. Tare.
A relic of cultivation, Raasay.

V. angustifolia L. Spring Vetch.
Amongst grass near the Mermaids, Raasay, and supplying a new county record.

LATHYRUS.

L. pratensis L. Yellow Vetchling.
Common in fields, on path sides, etc., Raasay, Scalpay, Rona.

L. montanus Bernh. Tuberous-rooted Bitter Vetch.
Of free occurrence on Raasay and Scalpay, not ascending far; the var. *tenuifolius* Garcke, grows near the Manse, Raasay.

ROSACEÆ.

PRUNUS.

P. avium L. Gean.
Fine, wellgrown trees, fruiting freely, were observed in the woods on the south side of Scalpay; new to V.C.104.

P. Padus L. Bird Cherry.
Very rare in the "amphitheatre" along Allt Liath, Scalpay; certainly native, as the Eriophyid mite gall produced by *Eriophyes padi* abounds on it.

SPIRÆA.

S. Ulmaria L. Meadow Sweet.
On marshy ground everywhere, although not seen on Longay.

RUBUS.

R. idæus L. Rasp.
On Raasay, Rona, and Scalpay, thickets, pathsides, etc., plentiful.

R. Rogersii Linton
Scattered on Raasay.

R. suberectus Anders. Bramble.
In the wood along the Arish Burn.

R. rhamnifolius W. and N.
S. Scalpay and Raasay.

R. villicaulis Koehl.
Along the coast, when it rises gently; West Raasay and Rona.

R. Selmeri Lind.
On all the Islands.

R. rusticanus Merc.
Raasay and Longay.

R. radula Whe.
Raasay House area.

R. corylifolius Sm.
Inverarish Woods.

R. cæsius L. Dewberry.
Open spaces near Inverarish; a new county record.

R. saxatilis L. Stone Bramble.
Rough stony places, local, but common on Raasay along the cliffs between Inverarish and Churchtown Bay and Hallaig; also on Scalpay in similar places.

R. idæus X R. suberectus.
This hybrid was detected in the woods along the Arish Burn; a shy fruiter.

DRYAS.

Dryas octopetala L. Mountain Avens.
In enormous quantities on the limestone cliffs from Screapadal to Rudha na Leac, where it descends to sea-level; it does not occur above 800 feet and leaves the sea for only a short distance at about 550 feet near the fissures, Hallaig; also found as a small isolated colony on the most inland of the conglomerates of the vents behind Brochel. Its abundance on Raasay is a strange contrast to its rarity on the Ross-shire mainland across the Inner Sound.

GEUM.

G. urbanum L. Wood Avens.
One of the common British plants so unaccountably absent, or rare, in these islands; in small quantity at Screapadal, Brochel, and Hallaig. Previously, vice-county 104 was the only British or Irish area from which it was supposed to be absent; this, therefore, forms a new county record.

G. rivale L. Water Avens.
In all kinds of places, even cliff ledges, on Raasay, Scalpay, and Rona.

G. rivale X G. urbanum (=intermedium Ehr.) Hybrid Avens.
In small quantity near Screapadal; also new to vice county 104.

FRAGARIA.

F. vesca L. Strawberry.
Widespread on Raasay; local on Scalpay.

POTENTILLA.

P. sterilis Garcke Barren Strawberry.
Like *G. urbanum*, very rare on Raasay; near Inverarish only.

***P. erecta** Hampe Tormentil.
Widespread on all the islands.

P. Anserina L. Silver Weed.
In waste places, everywhere except on Longay; often as a shingle plant on Raasay.

P. palustris Scop. Marsh Cinquefoil.
Very local indeed, Loch a Chadhacharnaich, Raasay; Loch Braig, Rona; marshy ground, south side of Scalpay. Druce calls it a "calcifuge," but in its Raasay station the amount of calcium carbonate it endures is great.

ALCHEMILLA.

A. arvensis Scop. Parsley Piert.
In waste places and on bare patches of soil; rare, Raasay and Scalpay.

A. minor Huds. Lady's Mantle.
Not uncommon on grassy places, formerly disturbed, on Raasay; distinctly rare on Scalpay; new to V.C. 104.

A. alpestris Schmidt Lady's Mantle.
Along the paths leading to Dun Caan, but probably widely spread in similar places; only noted on Raasay.

A. alpina L. Alpine Lady's Mantle.
Very common on Dun Caan, especially on the western slopes of its "cap", on rocks on Rona, and one plant only on the shores of Loch an Leoid, Scalpay.

ACÆNA.

A. microphylla Hook f.
A New Zealand plant thoroughly naturalised so as to form a sward, with various Agrostis and Festuca species, on the coast between the Pier and Suisnish Point; also at 600 feet up the Arish Burn.

AGRIMONIA.

A. odorata Mill. Agrimony.
Only at three points, near the Mermaids, North Fearns, and Eyre Point, all on Raasay. A new county record.

ROSA.

***R. spinosissima** L. Burnet Rose.
The distribution of this rose affords one of the most baffling problems in geographical distribution on the islands. It occurs everywhere on Scalpay, on the margins, and in the ravines, of every mountain torrent down to the mouth, on the sandstone and other cliffs on S. Scalpay, as well as on low-lying conglomerates in the north. It also occurs on Skye opposite Inverarish. In spite of this, careful and sustained searches on Raasay, Rona, Fladday, and Longay have definitely demonstrated its absence on those islands.

(a) Var. **typica** W.D. This form predominates on Scalpay.
(b) Var. **pimpinellifolia** L. Not uncommon along the streams entering the sea on the northern side of the island.
(c) Var. **Ripartii** Déségl. A strongly marked form of this variety grows at the mouth of Allt Camas na Geadaig.

R. spinosissima X R. canina (agg.)
S. Fearns, Raasay.

R. spinosissima X R. Sherardi.
S. Fearns, Raasay, N. Scalpay. It will be noticed that, although no *spinosissima* grows on Raasay, these hybrids occur; opposite the Raasay station, Caol Mohr, separating Raasay from Scalpay, is about one mile wide.

R. canina L. (agg.)

Lutetianæ group.
- (a) Var. **lutetiana** Baker, Longay and Rona only.
  - (1) f. **lasiostylis** Borb. Brochel.
- (b) Var. **flexibilis** Déségl. Clachan, Raasay.
- (c) Var. **senticosa** f. **oxyphylla** Rip. Rona.

Transitoriæ group.
- (d) Var. **spuria** Pug. Fearns, Raasay.
  - (1) f. **syntrichostyla** Rip. Arnish, Torran, Brochel, N. Raasay, Rona, Longay.
- (e) Var. **globularis** Franch. Cliffs, S. Scalpay.
- (f) Var. **ramosissima** Rau. Arnish, Torran, Brochel, N. Raasay; S. Scalpay.

Dumales group.
- (g) Var. **dumalis** Bechs. Torran, Arnish, Brochel, North Raasay; Rona.
  - (1) f. **viridicata** Pug. Balachuirn, North Fearns, Raasay; S. and W. Scalpay.
  - (2) f. **cladoleia** Rip. N. Fearns, Raasay.
- (h) Var. **biserrata** Mér. West of Point of Eyre Lighthouse.
  - (1) f. **sphæroidea** Rip. Balachuirn.
- (i) Var. **carioti** Chab. Brochel, N. Fearns, Raasay; Allt Liath, E. Scalpay, also W. Scalpay.
- (j) Var. **fraxinoides** H. Br. Common N. and S. Fearns, Eyre, Raasay and S. Scalpay.
- (k) Var. **Schlimperti** Hoffm. Widespread and common on Raasay from Eyre to Torran; S. Scalpay.
- (l) Var. **sylvularum** Rip. S. Fearns, Raasay.
  - (1) f. **adscita** Déségl. Brochel and Clachan, Raasay; Fladday.

Andegavenses group.
- (m) Var. **verticillacantha** Mér. Plentiful near Arnish and Torran, and rare, N. Fearns, Raasay.
- (n) Var. **Schottiana** Ser. N. and S. Fearns, Raasay.

R. glaucophylla Winch (agg.)

Reuterianæ group.
- (a) Var. **Reuteri** God. Along the Arish Burn, Raasay; Scalpay.
  - (1) f. **transiens** Gren. W. Scalpay.
- (b) Var. **subcristata** Baker. Raasay House grounds, Eyre, Fearns, Clachan, Raasay; Allt Liath, Scalpay.
  - (1) f. **jurassica** Rouy. Screapadal and Fearns, Raasay; S. Scalpay.
  - (2) f. **myriodonta** Chr. Clachan, Balachuirn, Hallaig, Raasay.
  - (3) f. **adenophora** Gren. S. Scalpay.

Subcaninæ group.
- (c) Var. **subcanina** Chr. Brochel, Screapadal, Balachuirn, Fearns, Raasay.
- (d) Var. **denticulata** R. Kell. S. Fearns.
- (e) Var. **pseudo-Haberniana** R. Kell. Clachan.
- (f) Var. **Diodus** R. Kell. Torran, N. Raasay.

R. mollis Sm. (agg.)
(a) Var. **glandulosa** W.D. This species has proved to be exceptionally rare on these islands, and one clump near Suisnish Rock, Raasay, and one on Rona, belonging to the present variety, are all that careful searches have disclosed.

R. Sherardi Dav. (agg.)
(a) Var. **typica** W.D. N. and S. Fearns, Raasay.
(1) f. **submollis** Ley. Everywhere on the lower ground on Raasay, Rona, S. Scalpay.
(2) f. **pseudomollis** Ley. Also widespread on Raasay, and sparingly on Scalpay, where it occurs from sea-level to 700 feet.
(3) f. **uncinata** Lees. Balachuirn, Clachan.
(b) Var. **omissa** Déségl. Rona, Raasay, Scalpay, sparingly.
(c) Var. **Woodsiana** Groves. Arnish, Torran and Clachan, Raasay, sometimes with white flowers, Rona, Scalpay.
(d) Var. **suberecta** Ley. Sparingly from Torran to Clachan and S. Fearns, Raasay.
(e) Var. **glabrata** Ley. We do not regard this as being a mere form of var. *suberecta.* It has a very wide spread of variation, which we propose to discuss elsewhere, and is the commonest and most widely spread rose in the islands, occurring on all, and also on Skye, near Sconser.
(f) Var. **eminens** Harr. A form exceedingly near this Durham plant, on Allt Liath, Scalpay.
(g) Var. **cinerascens** Dum. Very rare, Rona.
(h) Var. **perthensis** Rouy. This is the extraordinary form, with heavy armature, formerly thought to be a hybrid between *R. Sherardi* and *R. spinosissima.* It was first discovered by the late Mr. W. Barclay near Auchterarder station in Perthshire, and subsequently by Heslop Harrison at Forres. Later, cytological and cultural experiments demonstrated that it was not a hybrid, but a true *Sherardi* form, and this view is now generally adopted. The form growing at Fearns is not so extreme as the wild Auchterarder plants, but does not differ significantly from plants grown in the garden at Birtley from wild Perthshire seeds.

R. Sherardi X R. verticillacantha.
This beautiful well grown hybrid, flowering well, but producing fruits with few or no seeds, and even aborting many fruits, grows near Torran. In our view this hybrid formed the starting point for the development of the plant called *R. Sherardi* var. *glabrata.*

R. Sherardi var. **typica X R. Sherardi** var. **glabrata.**
A form exactly intermediate between these two plants was found near Fearns, and judged to be a hybrid with the parentage stated.

SORBUS.

S. aucuparia L. Mountain Ash.
Common enough, cliffs, woods, and ravines on all the islands.

S. rupicola Hedl.
Rare on limestone cliffs just north of Rudha na Leac; new to V.C. 104.

CRATÆGUS.

C. monogyna Jacq. Hawthorn.
Rare along the Arish Burn, commoner near S. Fearns on the slopes leading to the shore; very variable.

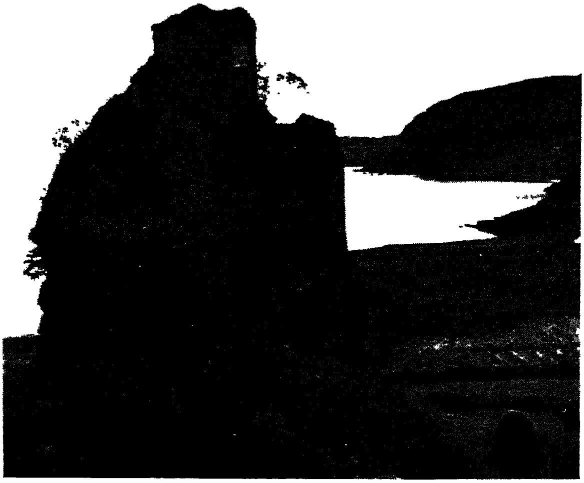

Fig. 13. The Volcanic Vent with Brochel Castle; Cliffs at Screapadal behind.

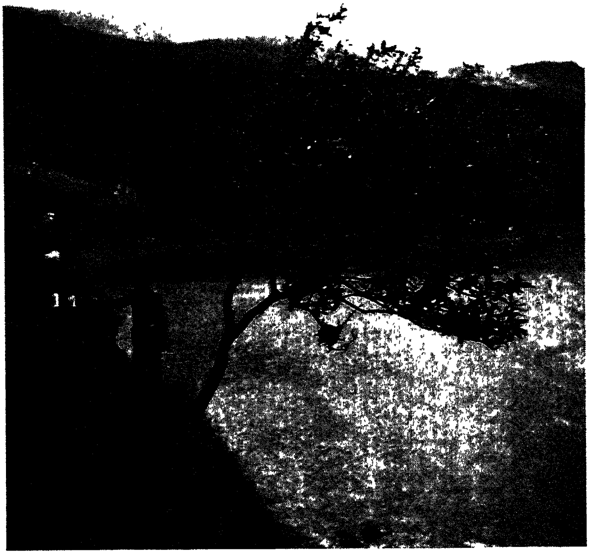

Fig. 14. *Sorbus rupicola* on the Cliffs near Rudha na Leac.

COTONEASTER.

Cotoneaster Simonsii Baker. Cotoneaster.
Seeding itself and growing below the cliffs between Inverarish and the Pier, Raasay.

SAXIFRAGACEÆ.

SAXIFRAGA.

S. aizoides L. Golden Saxifrage.
On the cliffs and slopes from N. Fearns to Screapadal, chiefly where water trickles down; rare near Loch na Mna, Raasay. One station is at sea-level.

S. hypnoides L. Mossy Saxifrage.
Common and variable on the cliffs to the east of Dun Caan, descending to about 500 feet, plentiful on the shores of Loch na Meilich, as well as on the escarpment west of Beinn na Leac.

TELLIMA.

T. grandiflora R. Br.
Established on roadsides near Raasay House.

CHRYSOSPLENIUM.

C. oppositifolium L. Opposite-leaved Golden Saxifrage.
Common in wet shady places, even in caves, as on Rona and Longay; penetrates deeply into dark crevices in the conglomerate of Scalpay; on all the islands except Fladday.

PARNASSIA.

P. palustris L. Grass of Parnassus.
Very rare in view of its abundance on Skye; only on the shores of Loch a Chadhacharnaich, Raasay.

CRASSULACEÆ.

SEDUM.

***S. roseum Scop.** Roseroot.
On cliffs in the east of Raasay. It ascends Dun Caan to a height of 1456 feet from the rocks, almost at sea-level, under Hallaig Waterfall. It also occurs sparingly on the western slope of the "cap" of Dun Caan, but does not pass to the cliffs fringing the west of Raasay. On Rona, on the other hand, it grows on the cliffs in the west, and also on Eilean Garbh. The cliffs on Fladday and northern Scalpay also support strong colonies.

S. anglicum Huds. English Stonecrop.
On rocks near the sea on all the islands; may have white or pinkish flowers. On Longay, it may be seen growing satisfactorily enough amongst sphagnum in the centre of the island.

DROSERACEÆ.

DROSERA.

D. anglica Huds. Long-leaved Sundew.
On the barer edges of bogs, plentiful everywhere, except on Longay.

D. rotundifolia L. Round-leaved Sundew.
Very abundant in boggy "slacks" etc. on the moorlands; on all the islands.

D. obovata Koch (D. anglica X D. rotundifolia).
Sparingly, with the parents, on Raasay.

HALORAGACEÆ.

MYRIOPHYLLUM.

M. spicatum L. Spiked Water Milfoil.
Rare in smaller pools on Scalpay; new to V.C. 104.

M. alterniflorum DC. Water Milfoil.
Loch Eadar da Bhaile, Raasay; Loch Braig, Rona, and the lower lochs on Scalpay.

CALLITRICHE.

C. vernalis Koch. Starwort.
On Raasay; rare, Loch na Mna, a new county record.

C. stagnalis Scop. Starwort.
Common enough in rills, damp places, etc., Raasay, Scalpay and Rona.

C. intermedia Hoffm. Starwort.
In Loch na Meilich, Raasay, in Loch Braig, Rona, and Loch an Leoid, Scalpay.

C. autumnalis L. Starwort.
Loch na Mna, on Raasay.

LYTHRACEÆ.

LYTHRUM.

L. Salicaria L. Purple Loosestrife.
Exceptionally plentiful in marshy places, even near the sea, throughout Rona north of Big Harbour. This is remarkable in view of its absence on Raasay and Scalpay. A new county record.

ONAGRACEÆ.

EPILOBIUM.

E. angustifolium L. Rosebay Willow Herb.
Very rare on rocks near Screapadal and to the east and south-east of Dun Caan, Raasay; on a cliff along Allt Liath, Scalpay The flowers are of a much duller colour, inclined to purple, than the prevalent plant in Northumberland and Durham.

E. montanum L. Willow Herb.
Everywhere on all the islands.

E. tetragonum L. Willow Herb.
Sparingly near Brochel, and down the east coast of Raasay; also on Scalpay. New to V.C. 104.

***E. palustre** L. Marsh Willow Herb.
Generally distributed on the islands.

FUCHSIA.

F. Riccartoni Hort.
In many stations around Inverarish and Raasay House.

CIRCÆA.

C. lutetiana L. Enchanter's Nightshade.
Local in Raasay House grounds, and near the salmon fishers' huts, Brochel, Raasay; in the wood on Scalpay.

C. alpina L. Alpine Enchanter's Nightshade.
Amongst shaded rocks near Brae, along Loch Eadar da Bhaile, and Hallaig, Raasay; also west of Loch Braig, Rona; a new county record.

UMBELLIFERÆ.

HYDROCOTYLE.

H. vulgaris L. Marsh Pennywort.
Locally plentiful on Rona, more sparingly on Raasay and Fladday.

SANICULA.

S. europæa L. Wood Sanicle.
In woodlands and shady places generally; on Raasay, Rona, and Scalpay.

ÆGOPODIUM.

A. Podagraria L. Goutweed.
Not uncommon in, and about, Raasay House grounds, near Brae, Raasay, and in the extreme south of Scalpay.

CONOPODIUM.

C. majus Loret. Earthnut.
Not very plentiful, and somewhat local, on Raasay; often in birchwoods.

ANTHRISCUS.

A. sylvestris Hoff. Wild Chærophyllum.
Quite rare north of Inverarish.

ŒNANTHE.

Œ. crocata L. Water Dropwort.
Locally plentiful as at Oskaig, and Screapadal on Raasay, above Dry Harbour, Rona, in the marshes near the houses on Scalpay, Fladday, and a very few examples on Longay.

LIGUSTICUM.

***L. scoticum** L. Lovage.
On cliffs northward from Inverarish, Raasay, and at similar points on Rona; apparently restricted to the western shores of both islands.

ANGELICA.

A. sylvestris L. Angelica.
Everywhere abundant.

HERACLEUM.

H. Sphondylium L. Cow Parsnip.
Rare and local; on Raasay on the edges of woods near the Post Office, and on Scalpay near Scalpay House.

DAUCUS.

D. Carota L. Wild Carrot.
Chiefly on banks, and occasionally abundant, Oskaig, Brochel, Balachuirn, Raasay; also on Rona and Fladday.

CAUCALIS.

C. Anthriscus Huds. Hedge Parsley.
Rare; near the ruins of Brochel Castle only.

ARALIACEÆ.

HEDERA.

H. Helix L. Ivy.
Plentiful everywhere, even on Longay, on sea cliffs; only rarely on trees. This abundance is in strange contrast to its rarity on the mainland opposite.

CAPRIFOLIACEÆ.

ADOXA.

A. Moschatellina L. Moschatel.
In deep shade amongst the rocks on the burn entering Camas na·Geadaig, Scalpay; not found elsewhere. New to V.C. 104.

SAMBUCUS.

S. nigra L. Elder.
In woods, S. Raasay and S. Scalpay; local.

VIBURNUM.

V. Opulus L. Guelder Rose.
Very rare; along Allt Liath, Scalpay, only.

LONICERA.

L. Periclymenum L. Honeysuckle.
Common and widely distributed in woodlands, ravines, and amongst rocks; even on the moorland on Longay.

SYMPHORICARPUS.

S. racemosus Michx. Snowberry.
Naturalised, and common in woods on Raasay and Scalpay.

RUBIACEÆ.

GALIUM.

***G. saxatile** L. Heath Bedstraw.
Common everywhere.

G. pumilum Murray.
On limestone exposures on Beinn Loch a Mhuilinn, Scalpay, and in a similar station at Screapadal, Raasay; new county record.

G. palustre L. Marsh Bedstraw.
Widespread and common in marshes.

G. Aparine L. Cleavers.
Mainly a shingle plant, and common on all the islands; very variable.

ASPERULA.

A. odorata L. Woodruff.
Locally distributed in birchwoods on Raasay and Scalpay.

VALERIANACEÆ.

VALERIANA.

V. sambucifolia Mik. Valerian.
Widespread and exceedingly variable on Raasay, Scalpay, and Rona.

V. officinalis L. Valerian.
This plant is widely spread on Raasay in the form of var. *dentatifolia* Druce, and in the south of Scalpay as var. *latifolia* Vahl; a new county record.

DIPSACACEÆ.

SCABIOSA.

***S. Succisa** L. Devil's Bit Scabious.
Practically everywhere and abundant.

COMPOSITÆ.

EUPATORIUM.

E. cannabinum L. Hemp Agrimony.
Chiefly in damp places on cliffs, but not uncommon; Raasay, Scalpay, Fladday, Rona. Its general distribution on these islands contrasts with its absence in West Ross.

SOLIDAGO.

***S. Virgaurea** L. Golden Rod.
Common on all the islands, especially Longay, where it often monopolises whole areas. Forms, possibly assignable to var. *cambrica*, occur on Dun Caan.

BELLIS.

***B. perennis** L. Daisy.
Quite common.

ASTER.

A. Tripolium L. Sea Aster.
Rare; salt marsh near Oskaig, Raasay; on Dry Harbour, Rona.

ANTENNARIA.

A. dioica Gært. Mountain Everlasting.
Common on hills amongst grass, but also in cracks on flat, exposed rocks.

GNAPHALIUM.

G. uliginosum L. Marsh Cudweed.
Local on path sides, Raasay, Fladday.

G. sylvaticum L. Heath Cudweed.
Local in woods and heaths; not found on Longay or Scalpay.

INULA.

I. Helenium L. Elecampane.
Rare, near the ruins of Brochel Castle, Raasay, and in the South of Scalpay; new to V.C. 104.

ACHILLEA.

A. Millefolium L. Yarrow.
Generally distributed and common.

A. Ptarmica L. Sneezewort.
Also common and widespread; a form without ray florets and possessing a disc double its usual diameter was collected near Suisnish.

CHRYSANTHEMUM.

C. segetum L. Corn Marigold.
In oatfields on Raasay, Scalpay, and Fladday, although not very plentiful.

C. Leucanthemum L. Ox-eye Daisy.
Quite local; Raasay, Scalpay.

MATRICARIA.

M. inodora L. Mayweed.
Common in most places; form *maritima* on Scalpay, Rona, and near the Pier, Raasay.

M. suaveolens Buchenau.
Waste places, Scalpay and Raasay. New to V.C. 104.

TANACETUM.

T. **vulgare** L. Tansy.
Very local, and perhaps introduced; along Loch Eadar da Bhaile, and near Eyre Point.

TUSSILAGO.

T. **Farfara** L. Coltsfoot.
On Scalpay and Raasay; bare ground, but not common.

PETASITES.

P. **ovatus** Hill. Butterbur.
Under the cliff at Brochel, Raasay.

SENECIO.

S. **vulgaris.** L. Groundsel.
Not on Fladday or Longay; locally plentiful elsewhere.

S. **Jacobæa** L. Ragwort.
Does not ascend high, but is generally distributed; var. *discoideus* near Inverarish, where plants with cream coloured flowers are not infrequent.

S. **aquaticus** Hill. Marsh Ragwort.
Also quite general on the lower areas.

ARCTIUM.

A. **nemorosum** Lej. Burdock.
Sparingly distributed throughout. New to V.C. 104.

A. **minus** Bernh. Burdock.
Possibly widespread, but only critically examined in the area between Eyre and Fearns, Raasay.

CARDUUS.

C. **nutans** L. Musk Thistle.
Very local on Rona.

CNICUS.

*C. **lanceolatus** Willd. Spear Thistle.
Abundant except on Longay.

C. **palustris** Willd. Marsh Thistle.
Common everywhere.

C. **heterophyllus** Willd. Melancholy Thistle.
Local on Raasay; Brochel to Hallaig, Balachuirn, and rare on the Arish Burn.

C. **arvensis** L. Common Thistle.
Common except on Longay.

CENTAUREA.

C. **obscura** Jordan. Knapweed.

C. **nemoralis** Jordan. Knapweed.
Both of these microspecies occur, but their exact distributions are unascertained.

LAPSANA.

L. **communis** L. Nipplewort.
Not common on Raasay and Fladday.

CREPIS.

*C. **capillaris** Wallg. Smooth Hawk's-beard.
Quite frequent on the more low-lying grassy places on Raasay, Scalpay, and Rona.

C. paludosa Mœnch. Marsh Hawk's-beard.
Widespread and variable in suitable localities on all the islands explored.

HIERACIUM.

H. iricum Fr. Hawkweed.
Ravines on Allt Camas na Geadaig, Scalpay.

H. anglicum Fr.
Near Loch Eadar da Bhaile, and on the cliffs at Hallaig.

H. flocculosum Backh.
The var. *longibracteatum* F.J.H. is to be found along the Arish Burn, Raasay.

H. caledonicum F.J.H.
On a cliff in the gorge of the Allt Liath on Scalpay.

H. argenteum Fr.
On Dun Caan, Raasay.

H. vulgatum Fr.
Widely spread and not uncommon along the burns on Raasay, also on banks near Brochel on the same island.

H. pseudonosmoides Fr.
South Fearns, Raasay.

H. auratum Linton.
South Fearns, Raasay, and also in the ravines on Scalpay.

H. crocatum Fr.
Near Brochel, Raasay, and not uncommon along the burns on Scalpay.

H. strictum Fr.
Screapadal, Raasay.

H. obliquum Jord.
On the slopes just west of Brochel.

H. Pilosella L. Mouse-ear Hawkweed.
Very rare on dry banks above Inverarish, commoner in a ravine just where the burn enters the sea near Eyre Point, Raasay, also in South Scalpay.

H. pernigrescens Zahn.
Stony ground near South Fearns, Raasay.

H. concinnatum F.J.H.
Rare in the south-west of Scalpay.

HYPOCHŒRIS.

H. radicata L. Cat's Ear.
Common enough at all points except on the moorlands.

LEONTODON.

L. autumnale L. Hawkbit.
Generally distributed; the var. *sordidum* also occurs.

TARAXACUM.

T. vulgare Schr. Dandelion.
Thinly spread on Raasay, South Rona, and Scalpay.

***T. paludosum** Schl.
On the east coast of Rona opposite Dry Harbour, where the small stream enters the sea.

T. spectabile Dahl.
In damp places, Scalpay and Raasay.

SONCHUS.

S. oleraceus L. Sow Thistle.
Waste places, everywhere.

S. asper Hill. Sow Thistle.
Generally distributed.

CAMPANULACEÆ.

LOBELIA.

L. Dortmanna L. Water Lobelia.
In lochs on all the islands except Longay; more plentiful in the lower-lying ones.

VACCINIACEÆ.

VACCINIUM.

V. Myrtillus L. Blaeberry.
Abundant and generally distributed; extraordinarily luxuriant in the lower gorge of Storab's Burn.

V. Vitis-Idæa L. Cowberry.
Very rare; only found on Dun Caan and on the slopes of a tributary of the Arish Burn, two miles south of the former station.

ERICACEÆ.

ARCTOSTAPHYLOS.

A. Uva-ursi Spr. Bearberry.
Abundant from sea level to the highest possible elevations on rocky slopes; on all the islands.

CALLUNA.

***C. vulgaris** L. Heather.
Very abundant; var. *incana* Reich. not common; var. *alba* Dr. sporadically; var. *arborescens* D. T. and H. on Longay only.

ERICA.

***E. cinerea** L. Fine-leaved Heath.
Plentiful everywhere; flaked pink and white flowered forms on Longay.

***E. Tetralix** L. Cross-leaved Heath.
Very common, with white flowered forms occasionally.

RHODODENDRON.

R. ponticum L. Rhododendron.
Completely naturalised, and seeding itself on Raasay.

PYROLA.

P. minor L. Winter Green.
Near Screapadal, Raasay only; rare.

P. secunda L.
Very rare and local; on the cliff Gualann na Leac; in the gorge of the Storab Burn near Balachuirn.

PLUMBAGINACEÆ.

ARMERIA.

***A. maritima** Willd. Sea Pink.
Common on the rocks and cliffs, and more rarely in salt marshes; in all probability, two subspecies occur.

PRIMULACEÆ.

PRIMULA.

P. vulgaris L. Primrose.
Woods, banks, and cliffs, everywhere abundant; at high water mark under the cliffs on Longay.

LYSIMACHIA.

L. nemorum L. Yellow Pimpernel.
Common and generally distributed on all of the islands.

GLAUX.

G. maritima L. Sea Milkwort.
Far from common; Oskaig, N. Fearns, Raasay; Dry Harbour, Rona; southern salt marsh and the mouth of Allt Liath, Scalpay.

ANAGALLIS.

A. arvensis L. Scarlet Pimpernel.
Very rare, introduced near Clachan, Raasay.

OLEACEÆ.

FRAXINUS.

F. excelsior L. Common Ash.
Local, but native, on Raasay, Brochel and Inverarish; planted on Rona at Big Harbour; native in the woods, S. Scalpay.

APOCYNACEÆ.

VINCA.

V. minor L. Periwinkle.
Probably an escape; near the Post Office, Raasay. New to V.C. 104.

GENTIANACEÆ.

ERYTHRÆA.

E. Centaurium Pers. Centaury.
Only found on Rona; in a hollow just north of the deserted village of Dry Harbour, and on Big Harbour.

CICENDIA.

C. pusilla Griseb.
This seems a very remarkable species to be discovered on Raasay but, after our own determinations, living plants were sent directly from Raasay to Kew and Edinburgh Botanical Gardens and verified. About three dozen plants were discovered in a hollow along a tributary of the Arish Burn just under the metal bridge crossing the Fearns Road. The examples examined were mostly very small. New to Britain, although on record for the Channel Islands.

GENTIANA.

G. campestris L. Field Gentian.
Local; behind Oskaig Point, east slopes of Dun Caan, and extremely abundant south of the Pier. Raasay.

MENYANTHES.

M. trifoliata L. Bog Bean.
Lochs, moorland pools etc.; common but not general.

BORAGINACEÆ.

SYMPHYTUM.

S. tuberosum L. Comfrey.
Raasay House grounds; new to V.C. 104.

MYOSOTIS.

M. cespitosa Schultz. Forget-me-not.
Local in wet places; all islands.
M. palustris Hill.
Rare in woods along the Arish Burn; new to V.C. 104.
M. repens G. and D. Don.
Common on all the islands.
M. sylvatica Hoff.
Rare in the woods near the Post Office, Raasay.
M. arvensis Hill.
Waste places, Raasay and Rona.
M. versicolor Sm.
Fairly frequent in dry places, but not on Rona.
M. brevifolia C.E.S.
Scattered in wet places on Raasay and Scalpay. New to V.C. 104; a recently described species.

CONVOLVULACEÆ.

CALYSTEGIA.

C. sepium R.Br. White Bindweed.
Probably an escape; Clachan and Inverarish, Raasay.

SCROPHULARIACEÆ.

LINARIA.

L. Cymbalaria Mill. Ivy-leaved Toadflax.
Abundant on walls near the Post Office.

SCROPHULARIA.

S. nodosa L. Figwort.
Common, but local, Raasay, Rona, Scalpay.

MIMULUS.

M. moschatus L. Monkey Musk.
An escape in the ditches along the Fearns road, Raasay.

DIGITALIS.

D. purpurea L. Foxglove.
Common, chiefly in ravines, on all the islands, but absent from the east of Raasay.

VERONICA.

V. agrestis L. Speedwell.
Cultivated ground generally.
V. persica Poir. Buxbaum's Speedwell.
Near Inverarish.
V. arvensis L.
On Raasay and Scalpay, on waste ground.
*__V. serpyllifolia__ L. Thyme-leaved Speedwell.
In damp grassy places on Raasay and Rona.
V. officinalis L.
Dry places and woods; Rona, Raasay, and Scalpay.
V. Chamædrys L. Germander Speedwell.
Widely spread except on Longay.
V. montana L. Mountain Speedwell.
In the woods along the Arish; local.

V. scutellata L.
In ditches etc., but local; Raasay and Rona.

V. Becca-bunga L. Brooklime.
Rare and local; North Fearns, near Storab's Grave, and also Inverarish, Raasay.

EUPHRASIA.

***E. borealis** Towns. Eyebright.
On paths, grassy moorlands, etc.; Raasay and Rona.

E. brevipila Burnat and Gremli.
S. Fearns, Inverarish to the Pier, Raasay; path on Beinn Loch a Mhuilinn, Scalpay.

E. confusa Pugsley.
Near Hallaig, Raasay, but probably widespread.

E. confusa X E. brevipila.
Inverarish.

E. curta Fr.
As a variety near *piccola* Townsh, on Dun Caan.

E. gracilis Fr.
On Raasay and Scalpay on the moors; well distributed.

E. scotica Wettst.
On rough ground near the iron mine, Raasay.

BARTSIA.

B. Odontites Huds. Red Bartsia.
Widespread, but not on Longay; generally in the vicinity of houses.

PEDICULARIS.

P. palustris L. Marsh Lousewort.
Common everywhere in boggy places.

P. sylvatica L. Lousewort.
Also abundant in damp places.

RHINANTHUS.

R. minor Ehrh. Yellow Rattle.
Thinly, but widely spread on the islands.

R. stenophyllus Schur.
Raasay, Rona, and Scalpay; not uncommon.

R. monticola Dr.
Sparingly under Dun Caan.

MELAMPYRUM.

M. pratense L.
Woods on Raasay, Rona, and Scalpay; very local. The var. *montanum* Johnst., occurs near Screapadal and on Big Harbour, Rona.

OROBANCHACEÆ.

OROBANCHE.

O. rubra Sm. Broomrape.
Very rare and local on Raasay; on thyme on the volcanic vent behind Brochel, cliffs near Hallaig, on the cliffs near Churchton Bay, and south of Holoman Island.

LENTIBULARIACEÆ.

UTRICULARIA.

U. major Schm. Bladderwort.
Rare, Loch Eadar da Bhaile, Raasay; Loch Braig, Rona.

U. minor L.
More widely spread, Raasay, Rona, and Scalpay.

U. ochroleuca Hartm.
In a shallow pool north of Loch an Uachdair, Raasay.

PINGUICULA.

P. vulgaris L. Butterwort.
Common, and generally distributed on all the islands.

P. lusitanica L. Pale Butterwort.
In barer places than the preceding species, from sea level on Camas na Geadaig, Scalpay, to about 600 feet; found on every island except Longay.

LABIATÆ.

MENTHA.

M. aquatica L. Mint.
Common enough.

M. arvensis L. Corn Mint.
Fields on Raasay and Scalpay.

THYMUS.

***T. Serpyllum** L. Thyme.
Common on all the islands; the segregates *pychnotrichus* Ronn., *Drucei* Ronn. and *neglectus* Ronn. all occur on Raasay.

T. ovatus Mill. Thyme.
Only observed on Raasay, south end of the island.

SCUTELLARIA.

S. galericulata L. Skullcap.
Local on Raasay, Rona, and Scalpay. The var. *littoralis* is plentiful on shingle on the same islands.

***S. minor** Huds. Lesser Skullcap.
In boggy places, locally abundant on Raasay; only on an islet in a small loch on Scalpay, near the centre of the island.

PRUNELLA.

***P. vulgaris** L. Selfheal.
Common everywhere; white flowered forms dominate some areas on Longay.

STACHYS.

S. sylvatica L. Hedge Woundwort.
In damp shady places; very local, Eyre, Inverarish, and Hallaig, Raasay, and near Scalpay House, Scalpay.

S. palustris L. Marsh Woundwort.
Common enough in oatfields etc.

S. ambigua (=S. palustris X S. sylvatica).
On ground once under cultivation, Inverarish.

GALEOPSIS.

G. speciosa Mill. Hempnettle.
In a field near North Fearns.

G. Tetrahit L. Hempnettle.
Widespread on all the islands except Longay; edges of fields etc.

LAMIUM.

L. purpureum L. Red Dead Nettle.
Cultivated ground near Inverarish, Raasay.

L. mollucellifolium Fr.
Also near Inverarish, but not on the same ground as the preceding species. New to V.C. 104.

TEUCRIUM.

***T. Scorodonia** L. Woodsage.
One of the commonest plants on dry ground.

AJUGA.

A. reptans L. Bugle.
Common universally.

PLANTAGINACEÆ.

PLANTAGO.

***P. maritima** L. Sea Plantain.
On the coasts of the various islands.

***P. coronopus** L. Stag's Horn Plantain.
Not very common, Rudha na Leac, Eyre region, and on Caol Rona, Raasay, rocks on Rona, on the north shores of Scalpay, and also on Fladday.

***P. lanceolata** L. Ribwort Plantain.
Common, but principally in the lowlands; the var. *sphærostachya* is also encountered.

P. major L. Plantain.
Waste places; common.

LITTORELLA.

L. uniflora Aschers. Shoreweed.
Quite abundant in the shallower lochs; Raasay, Rona, and Scalpay.

CHENOPODIACEÆ.

CHENOPODIUM.

C. album L. Goosefoot.
Common in most waste places, even on shingle.

ATRIPLEX.

***A. patula** L. Orache.
Locally on shingle; all islands.

A. hastata L.
Also local on the shores of Raasay and Scalpay.

A. glabriuscula Edmonst.
On shingle just north of the big cave on Rona.

SALICORNIA.

S. europæa L. Samphire.
In the salt marsh, Dry Harbour, Rona only.

POLYGONACEÆ.

POLYGONUM.

P. Convolvulus L. Black Bindweed.
Very rare indeed, Scalpay, Rona, and Raasay.

P. heterophyllum Lindm. Knotgrass.
Not at all common, but on all the islands.

P. Hydropiper L. Water Pepper.
Very rare at Fearns, Raasay, and on South Scalpay; commoner near the village of Dry Harbour, Rona.

P. Persicaria L. Spotted Persicaria.
In fields, only too plentiful everywhere.

P. viviparum L.
Generally rare on the limestone escarpment above Hallaig, but more abundant on rocks at the highest point.

P. cuspidatum Sieb. and Zucc.
An escape near Inverarish.

RUMEX.

R. glomeratus Schreb. Dock.
Rare near the Pier, Raasay; Rona.

R. obtusifolius L.
Common everywhere.

***R. crispus** L.
Common, also var. *trigranulatus* Syme.

R. longifolius L.
On Raasay, not uncommon in the south east.

***R. Acetosa** L. Sorrel.
Everywhere in grassy places.

***R. Acetosella** L. Sheep's Sorrel.
Abundant, but on more disturbed ground than the preceding.

EUPHORBIACEÆ.

EUPHORBIA.

E. Helioscopia L. Sun Spurge.
On cultivated ground near Oskaig, Raasay.

ULMACEÆ.

ULMUS.

U. montana L. Wych Elm.
One of the characteristic trees of the islands; in gorges and rocky places; as a pure "stand" in the wood along the north bank of the Arish Burn just outside of Raasay House grounds.

U. sativa Mill. Elm.
Planted, Scalpay.

URTICACEÆ.

URTICA.

U. dioica L. Nettle.
Everywhere near present and past habitations.

MYRICACEÆ.

MYRICA.

M. Gale L. Sweet Gale.
In boggy places on all the islands, plentiful.

BETULA.

B. alba L. Silver Birch.
Everywhere common, except on exposed moorlands.

B. pubescens Ehr. Birch.
Also common enough.

ALNUS.

A. rotundifolia Mill. Alder.
Stream sides and woods, but not on Fladday and Longay.

CORYLUS.

C. Avellana L. Hazel.
Plentiful along streams; occurs in the submerged forest in Dry Harbour, Rona.

QUERCUS.

Q. Robur L. Oak.
Q. sessiliflora Salisb.
Both of these occur in the Raasay House woods, in the wood near Big Harbour, Rona, and also in the deciduous woods adjoining Scalpay House. Both may be native, but one certainly is, for the characteristic Cynipid galls abound, as does also the oak Psyllid *Trioza remota.*

FAGUS.

F. sylvatica L. Beech.
This has the same distribution on the islands as the oaks but, significantly enough, no beech insects have been discovered.

SALICACEÆ.

SALIX.

S. fragilis L. Crack Willow.
Very rare near the Battery, Raasay.
S. viminalis L. Osier.
Rare and local, possibly planted; Balachuirn, Torran, and Inverarish, Raasay, Dry Harbour, Rona, and on Fladday.
S. aurita L. Sallow.
Abundant, but rarely above 1000 feet.
S. aurita X S. repens.
Sparingly where the parent species grow together.
S. aurita X S. cinerea.
Brochel and Balachuirn, Raasay.
S. Caprea L. Goat Willow.
Rare and local, Screapadal, Hallaig, the ravine near Storab's Grave, Raasay, and also on Scalpay. In some cases the foliage is much darker in colour than with us.
S. cinerea L. Sallow.
Thinly spread everywhere.
S. cinerea X S. viminalis.
Inverarish.
S. cinerea X S. repens.
Inverarish.
S. cinerea X S. Caprea.
Storab's Grave and Screapadal.
S. repens L. Creeping Willow.
From sea level to the top of Dun Caan; common enough on Raasay and Rona, but distinctly rare on Scalpay.
S. phylicifolia L. Tea-leaved Willow.
Rare, Torran and Balachuirn, Raasay.
S. herbacea L. Dwarf Willow.
At about 800 feet on cliffs near Screapadal, and at 1456 feet on the top of Dun Caan.

POPULUS.

P. alba L. White Poplar.
Planted in the wood near the Post Office, Raasay.
P. deltoida Marsh. Black Poplar.
Also introduced in the same area.
P. tremula Lange. Aspen
Common, but restricted to cliffs and rocks except on Longay, where some shrubs are to be found on the open moorland.

EMPETRACEÆ.

EMPETRUM.

***E. nigrum** L. Crowberry.
Abundant everywhere on moorlands.

ORCHIDACEÆ.

MALAXIS.

M. paludosa Sw. Bog Orchid.
Amongst Sphagnum in boggy places and around moorland pools; local near Suisnish Hill, and on a pool east of Holoman, Raasay, on the same islet on Scalpay as *Scutellaria minor.*

LISTERA.

L. ovata L. Twayblade.
Not uncommon on limestone near Screapadal and Rudha na Leac, Raasay, just above the old path in each case.

L. cordata Br. Lesser Twayblade.
Under bracken and heather on the open moorlands, but also amongst mosses in ravines; fairly frequent on Raasay and Scalpay.

EPIPACTIS.

E. atropurpurea Raf.
Very rare, on limestone in the gorge, and on the cliff face near Screapadal, Raasay.

ORCHIS.

O. mascula L. Early Purple Orchid.
Common enough in wooded areas on Raasay as at Brochel, Balachuirn etc.

O. incarnata L. Marsh Orchid.
In the marsh sloping to the sea north of the birch wood, near South Fearns, and near Torran, Raasay.

O. prætermissa Dr. Druce's Marsh Orchid.
Also in marshes in the Fearns area.

O. purpurella Stphns.
Frequent enough in marshes throughout Raasay, Rona, and Scalpay, the Rona localities producing extremely fine examples: a new county record.

O. purpurella X O. Fuchsii.
South east coast of Raasay.

O. elodes Gris. (=O. ericetorum Linton). Spotted Orchid.
Widespread in marshy places on the moors etc., but especially noticeable on a bank just above the path at Brochel, Raasay, also on Rona, Scalpay, and Fladday.

O. elodes X O. incarnata.
In the marsh, S. Fearns.

O. Fuchsii Druce.
Wet places generally, and occasionally abundant, as at South Fearns, and Eyre, Raasay, also on Scalpay and Rona; new to V.C. 104.

O. Fuchsii X O. elodes.
In the marsh near the shore at Fearns, Raasay.

GYMNADENIA.

G. conopsea Br. Fragrant Orchis.
Rare and local; only grows on limestone ledges above the path near the Waterfall, Hallaig, Raasay.

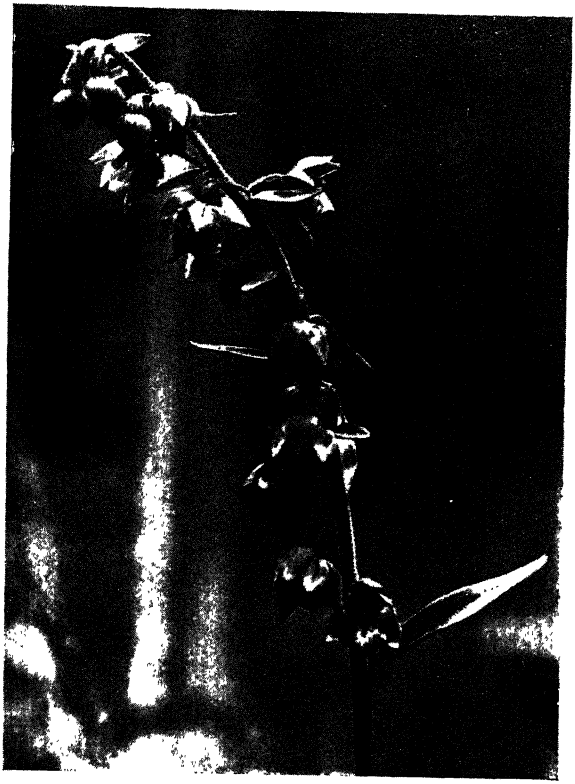

Fig. 15. *Epipactis atropurpurea* in Flower.

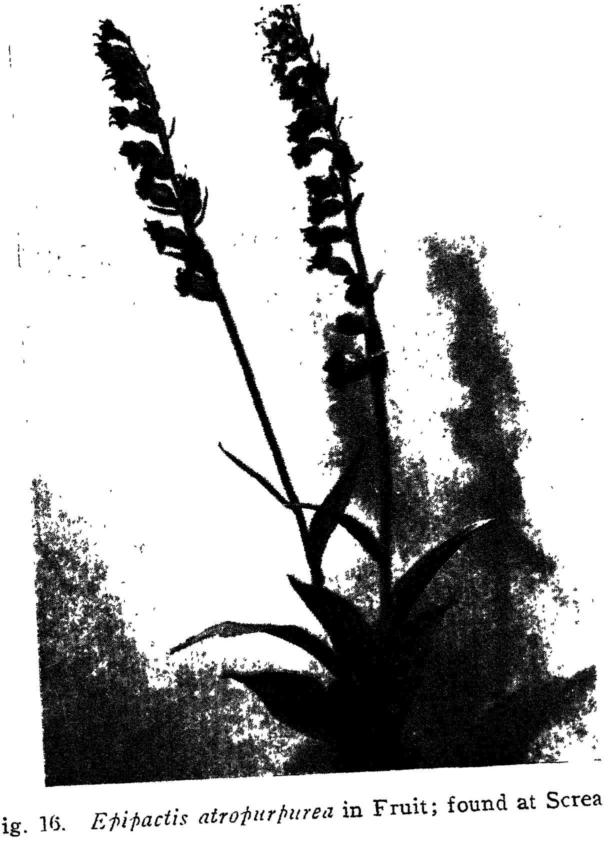

Fig. 16. *Epipactis atropurpurea* in Fruit; found at Screapadal.

LEUCHORCHIS.

L. albida Mey.
Local, in grassy places, near South Fearns, and Oskaig, Raasay.

COELOGLOSSUM.

C. viride Hartm. Frog Orchis.
Locally plentiful on grassy slopes behind Oskaig Point and near Screapadal, Raasay, Fladday, and on the edges of ravines, Scalpay.

PLATANTHERA.

P. bifolia Reich. Small Butterfly Orchid.
Not at all common, Fearns, Oskaig to Balachuirn, Raasay.

P. chlorantha Reich. Butterfly Orchid.
Very rare and local; west side of the ravine of the Allt Camas na Geadaig, Scalpay, and Screapadal, Raasay.

IRIDACEÆ.

IRIS.

I. Pseudacorus L. Yellow Iris.
In many marshy places on Raasay, Scalpay, and Rona.

TRITONIA.

T. crocosmæflora Hort. Montbretia.
A garden escape near Inverarish, Raasay.

LILIACEÆ.

POLYGONATUM.

P. multiflorum All. Solomon's Seal.
In the woods around Raasay House; possibly planted. New to V.C. 104.

ALLIUM.

A. ursinum L. Garlic.
Locally abundant amongst rocks, and in ravines; gorge of the Storab Burn, and Screapadal, Raasay; in ravines and rock crevices on the sea coast, North Scalpay.

SCILLA.

S. non-scripta Hoffm. and Link. Bluebell.
Abundant in woodlands, grassy places, and on cliff ledges; on every island.

NARTHECIUM.

N. ossifragum Huds. Bog Asphodel.
Common on boggy moorlands and by the sides of streams; absent only from Longay.

TOFIELDIA.

T. palustris Huds.
Very local on the lower slopes north west of Dun Caan.

PARIS.

P. quadrifolia L. Herb Paris.
One of the species confined to Scalpay; amongst rocks in the Allt Camas na Geadaig gorges in fair quantity; very rare in the ravine of the Allt Liath; a new county record.

JUNCACEÆ.

JUNCUS.

J. bufonius L. Toad Rush.
Plentiful everywhere on damp paths, in ditches etc.

***J. squarrosus** L. Rush.
Abundant on the moors.

J. Gerardi Lois.
In salt marshes and other damp places on the coast; common in suitable stations on all the islands.

J. macer S. F. Gray.
On the road from Inverarish to Fearns, and also behind the houses at Inverarish, Raasay. New to V.C. 104.

J. effusus L. Soft Rush.
Common on the moors; only reported from Raasay and Scalpay.

***J. conglomeratus** L.
Abundant on all the islands.

***J. bulbosus** L.
Frequent in damp places on the moors, ditches, etc., everywhere.

J. pygmæus Rich. Pygmy Rush.
As it had been noted that the common *J. bufonius* was exceedingly variable, big gatherings were made of that species. In one of these, collected between Oskaig and Holoman, on the path and on the moor, a specimen of this very rare plant (verified by W. H. Pearsall and A. J. Wilmott) turned up in 1935. Repeated searches on suitable ground in 1936 proved fruitless; new to Scotland and to V.C. 104.

***J. articulatus** L.
Very common everywhere.

J. sylvaticus Reich.
Abundant, but not on Fladday or Longay.

J. capitatus Weigel.
In 1936, on the occasion of one of our expeditions in search of *Juncus pygmæus,* this species was discovered in a damp stony hollow along a tributary of the Arish Burn, near the *Cicendia pusilla* station. More than two dozen plants were observed, and almost immediately the bulk was badly damaged by cattle. Unlike English examples of the species, some of these were viviparous. New to Scotland and therefore to V.C. 104. Fresh plants were sent directly from Raasay to Mr. W. H. Pearsall, and certified by him as being correctly identified.

LUZULA.

L. pilosa Willd. Wood Rush.
Sparingly, but widely distributed; a new county record, for V.C. 104., was the only vice county from which it had not been previously reported.

L. sylvatica Guad. Large Wood Rush.
Fairly general and common, on all the islands.

***L. campestris** DC. Field Wood Rush.
Abundant, and widely spread everywhere.

***L. multiflora** DC.
Frequently met with on all the islands.

TYPHACEÆ.

TYPHA.

T. latifolia L. Bulrush.
Very rare in the wood along the Arish Burn, Raasay, in a "backwater"; in Loch a Mhuilinn, Scalpay. A new county record.

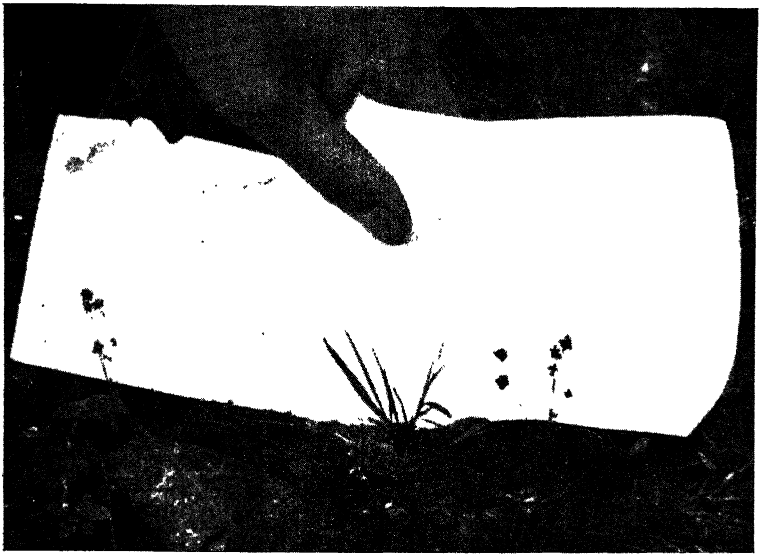

Fig. 17. *Juncus capitatus* in its Raasay Station.

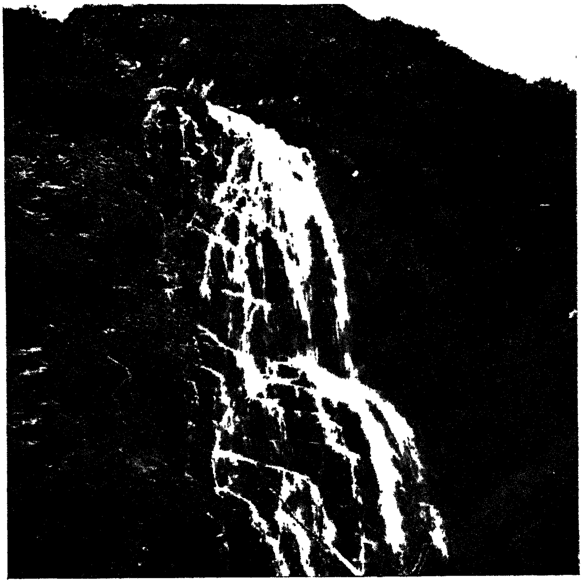

Fig. 18. The Habitat of the Royal Fern (*Osmunda regalis*) on Scalpay; the Waterfall on Allt Liath.

SPARGANIUM.

S. simplex Huds. Simple Burreed.
On all the islands save Longay; in lochs, but not really plentiful. New to V.C. 104. Specimens from Loch Eadar da Bhaile were examined by Mr. W. H. Pearsall.

S. angustifolium Michx. Floating Burreed.
Somewhat local in lochs on Raasay and Scalpay.

S. minimum Fr. Floating Burreed.
In lochs and pools on Raasay, Scalpay, and Rona, but not in great quantity.

NAIADACEÆ.

TRIGLOCHIN.

T. palustre L. Marsh Arrow Grass.
Damp places, everywhere except Longay.

T. maritimum L. Sea Arrow Grass.
Salt marshes and similar situations on Raasay, Scalpay and Rona; occasionally with the preceding species on Rona.

POTAMOGETON.

P. natans L. Pondweed.
Apparently only on Rona.

P. polygonifolius Pour. Pondweed.
In the form of var. *amphibius* and the type, quite widely distributed except on Longay.

P. lucens L. Shining Pondweed.
Rare; only in Loch na Meilich under the cap of Dun Caan.

P. perfoliatus L.
Dredged by Dr. Griffiths from lochs on Raasay.

P. crispus L.
Also collected by Dr. Griffiths and Miss Chalklin in the lochs on Raasay.

P. pectinatus L.
Local in several lochs on Raasay, and in Loch Braig, Rona; new to V.C. 104.

P. filiformis Pers.
In two or three of the lochs on Raasay; confirmed by Mr. W. H. Pearsall. New to V.C. 104.

RUPPIA.

R. maritima L.
Only in pools in the salt marsh south of Oskaig, Raasay, and there distinctly rare; a new county record.

ZOSTERA.

Z. marina L. Grass Wrack.
Not at all common; above Balachuirn at the mouth of the burn; shores of Longay and at the mouth of Allt Liath, Scalpay.

CYPERACEÆ.

ELEOCHARIS.

E. palustris Roem. and Schult.
Common in marshes etc.

E. multicaulis Sm.
Also abundant in wet situations.

SCIRPUS.

S. **pauciflorus** Lightf.
Moors, bogs, etc.; common.
S. **cæspitosus** L.
Very abundant on the moors.
S. **fluitans** L.
Rather common everywhere in pools etc.
S. **setaceus** L.
Wet places on Scalpay and Raasay; widespread.
S. **lacustris** L.
Very rare; in a small loch toward the northern extremity of Rona, in Loch an Leoid and Allt Liath on Scalpay, but seemingly absent from Raasay.
S. **rufus** Schrad.
Local in salt marshes; Rona, Oskaig, Raasay, and in the south of Scalpay.

ERIOPHORUM.

*E. **vaginatum** L. Cotton Grass.
Abundant everywhere on the moors on boggy ground.
E. **angustifolium** Roth. Cotton Grass.
Like the preceding species.
E. **latifolium** Hoppe. Cotton Grass.
Local on the moors in Raasay and Scalpay.

RYNCHOSPORA.

R. **alba** Vahl. Beaked Rush.
On damp moorlands, but not ascending far; plentiful except on Longay and Fladday.

SCHOENUS.

S. **nigricans** L.
Locally common, even at sea level in wet places; not on Longay and Fladday.

CLADIUM.

C. **Mariscus** Br.
Very rare; on the eastern shores of Loch Braig, Rona, only. In that station it is quite plentiful. New to V.C. 104.

CAREX.

C. **dioica** L.
Local and not plentiful; western Raasay and Rona.
C. **pulicaris** L. Flea Sedge.
Common upon every island; on heaths etc.
C. **pauciflora** Lightf.
Very local, on Raasay only, by Loch Storab and Loch Meall Daimh.
C. **vulpina** L. Fox Sedge.
Extremely rare, Raasay, near Rudha na Leac.
*C. **echinata** Murr.
Common on damp moors, all islands.
C. **remota** L.
Quite rare on the Arish Burn, Raasay; Rona.
C. **leporina** L.
Not at all common although wide-spread, Raasay, Scalpay, and Rona.
C. **rigida** Good.
Higher ground to the west of Dun Caan, Raasay.
*C. **Goodenowii** Gay.
Common everywhere.

***C. glauca** Scop. (diversicolor Crantz)
Common, and to be found on every island.

C. limosa L.
Rather rare; Raasay, by Loch Meall Daimh, and Loch Eadar da Bhaile; Scalpay, on a small loch in the centre of the island

C. pilulifera L.
Common on Raasay and Rona; not reported elsewhere.

C. caryophyllea Latour.
On Raasay and Scalpay; thinly distributed.

C. pallescens L.
In the woods along the Arish Burn, Raasay, and also in a similar position on N. Scalpay.

C. panicea L. Carnation Sedge.
Common enough except on Longay.

C. sylvatica Huds. Wood Sedge.
Rare on Raasay only, Screapadal, Storab's Grave, and Inverarish.

C. helodes Link.
Very rare, Screapadal, Raasay, only.

***C. binervis** Sm.
Common amongst heather everywhere.

C. distans L.
Sparingly near Balachuirn, Raasay; and in marsh in the south of Scalpay. New to V.C. 104.

C. fulva Host.
Not very common, Raasay and Fladday.

C. flava L.
Not common, but on all the islands except Longay.

C. Oederi Retz.
Around lochs and pools; not common generally, and absent from Fladday.

C. ampullacea Good.
Common, except on Longay.

C. vesicaria L.
Rare near Inverarish, Raasay; new to V.C. 104.

GRAMINEÆ.

PHALARIS.

P. arundinacea L. Ribbon Grass.
Very local, on the east coast of Raasay only.

ANTHOXANTHUM

***A. odoratum** L. Sweet Vernal Grass.
Very abundant on all the islands; var. *villosum* Lois, Fladday, and S. Fearns, Raasay.

ALOPECURUS.

A. geniculatus L. Floating Foxtail.
Wet situations, ponds etc., but not on Fladday.

A. pratensis L. Meadow Foxtail.
Very rare; Raasay and Scalpay.

PHLEUM.

P. pratense L. Timothy.
Only once, Inverarish, and then probably introduced.

AGROSTIS.

A. canina L.
Common on Raasay, Scalpay, and Rona; on the latter island very curious diseased forms occur.

*A. **alba** L. Fiorin.
Plentiful and variable; a glaucous form, with a long ligule and close panicle, was collected near the cave, Rona.

A. **tenuis** Sibthorpe.
Common, but not on Longay.

CALAMAGROSTIS.

C. **epigeios** Roth.
Common in two colonies along the east coast of Raasay; Screapadal and Rudha na Leac, in the last case at sea level. New to V.C. 104, and a considerable northward extension of its range.

AIRA.

A. **caryophyllea** L.
Not at all common; near Clachan, and on the Fearns road, Raasay.

A. **præcox** L.
Chiefly on paths and old walls; everywhere except Longay.

DESCHAMPSIA.

D. **cæspitosa** Beauv. Tufted Hair Grass.
Common enough generally, but not on Longay.

D. **setacea** Richter.
Very local on Raasay; in Loch Storab and one of the smaller pools to the east of the Brochel Road.

*D. **flexuosa** Trin. Wavy Hair Grass.
Plentiful on all the islands.

HOLCUS.

H. **mollis** L. Creeping Soft Grass.
Not very plentiful, but on every island.

*H. **lanatus** L. Yorkshire Fog.
Common generally, but only sparingly on Longay.

AVENA.

A. **pubescens** Huds. Downy Oat Grass.
Only in two stations on Raasay; near the ironstone mine and Screapadal.

A. **pratensis** L. Perennial Oat Grass.
Very rare, on the limestone near the Waterfall, Hallaig, and Screapadal, Raasay.

A. **sativa** L. Oats.
Casual, on Scalpay near the mouth of Allt Liath, very far indeed from cultivation.

ARRHENATHERUM.

A. **elatius** Mert. & Koch. Tall Oat Grass.
Common but not on Longay; var. *pauciflora* occurs on Raasay.

A. **tuberosum** Gilib. Bulbous Oat Grass.
Waste ground on Raasay, Scalpay, and Rona.

SIEGLINGIA.

*S. **decumbens** Bernh. Decumbent Heath Grass.
Common on most of the islands, but rare on Longay.

PHRAGMITES.

P. **communis** Trin. Common Reed.
The distribution of this grass is exceedingly curious. It abounds everywhere on Rona, but is very scarce on Raasay,

for it has only been observed in Loch Uachdair and near Screapadal. On Scalpay, it is only to be found in Loch na Leoid and the Allt Liath. Fladday likewise supports a small colony.

CYNOSURUS.

C. cristatus L. Crested Dog's Tail.
Common enough, but not on Longay.

MOLINIA.

M. cærulea Moench. Moor Grass.
Very abundant everywhere.

DACTYLIS.

D. glomerata L. Cock's Foot Grass.
Quite uncommon but collected on Raasay, Scalpay, and Fladday.

POA.

***P. annua** L. Annual Meadow Grass.
Plentiful; not on Longay.
P. pratensis L. Smooth-stalked Meadow Grass.
Common; Raasay and Scalpay.
P. trivialis L. Rough-stalked Meadow Grass.
Common, but not on Longay.

GLYCERIA.

G. fluitans L. Floating Sweet Grass.
Rather local; Raasay, Scalpay, and Rona.
G. declinata Breb.
Swampy ground on the south side of Scalpay; new to V.C. 104.
G. maritima Mert. & Koch.
Very local in salt marshes; Raasay, Scalpay, and Rona. On the latter island the plant appears to be very variable, but the variation may be due to disease.

FESTUCA.

F. bromoides Huds.
Local, in waste places near old houses; on all the islands except Longay.
F. capillata Lam.
Sparingly on Raasay and Scalpay; in addition to the type, a glaucous leaved form grows on these two islands, as well as on Fladday.
***F. ovina** L. Sheep's Fescue.
Only the var. *vivipara* occurs, but it is very abundant, even on the Longay cliffs.
***F. rubra** L. Red Fescue.
Common everywhere; var. *glaucescens* Heg. and Heer abounds near the sea.

BROMUS.

B. ramosus Huds.
Widespread in the Raasay woods.
B. sterilis L.
Very rare indeed; Inverarish. New to V.C. 104.
B. commutatus Schrad.
A weed of cultivation, occurring sparingly everywhere except on Longay; new to V.C. 104.
B. hordaceus L. Soft Brome Grass.
A weed on all the islands except Longay.

BRACHYPODIUM.

B. sylvaticum Beauv. False Brome Grass.
Locally common, except on Longay.

LOLIUM.

L. perenne L. Perennial Rye Grass.
Common; absent from Longay. The var. *tenue* grows on Raasay.

AGROPYRON.

A. caninum Beauv. Bearded Wheat Grass.
Very rare; on Raasay under the cliff along the west shore of Loch Eadar da Bhaile.

A. repens Beauv. Couch Grass.
Near the *A. caninum* just mentioned, with the var. *Vaillantianum.*

NARDUS.

***N. stricta** L. Moor Mat Grass.
Abundant on most of the islands, but rare on Longay.

CONIFERÆ.

JUNIPERUS.

J. communis L. Juniper.
Generally rare, but more plentiful in the northern portions of Rona; on Storab's Burn, Raasay; in the wood on Scalpay.

J. sibirica Burgs. Dwarf Juniper.
In cracks in bare rocks and similar places; not uncommon, Raasay, Rona, Scalpay, and Fladday; generally about 800 feet, but at sea level on Rona, and on a sea cliff near Rudha na Leac.

PINUS.

P. sylvestris L. Scots Pine.
On Raasay, Rona, and Scalpay; certainly, from the stumps left *in situ*, once native on Rona. Vice County 104 should, therefore, be removed from the bracket in Druce's Comital Flora.

LARIX.

L. europaea DC. Larch.
Established on Raasay, Rona, and Scalpay.

PICEA.

P. excelsa Link. Spruce.
As in the case of the larch.

FILICES.

HYMENOPHYLLUM.

H. tunbridgense. Sm. Filmy Fern.
In the gorge in the south east of Scalpay; rare, new to V.C. 104.

H. peltatum Desv. Filmy Fern.
Damp shaded rocks, chiefly in ravines.

PTERIS.

***P. aquilina** L. Bracken.
Abundant everywhere.

CRYPTOGRAMME.

C. crispa Br. Parsley Fern.
Very rare; rocks on Dun Caan.

Fig. 19. The Cave on Rona; many Species of Ferns grow here.

BLECHNUM.

*B. **Spicant** With. Hard Fern.
Common enough on bank sides, on the moors, etc.; not on Fladday.

ASPLENIUM.

*A. **Adiantum-nigrum** L. Black Spleenwort.
Common on rocks and walls in shady areas.

*A. **marinum** L. Sea Spleenwort.
Very fine and abundant on the sea cliffs of all the islands.

A. **viride** Huds. Green Spleenwort.
Not very common; on the east coast of Raasay and on the cliffs above; Rona, and cliffs on Scalpay.

*A. **Trichomanes** L. Spleenwort.
Common on all the islands.

*A. **Ruta-muraria** L. Wall Rue.
Widely spread on rocks; on all the islands except Longay.

A. **septentrionale** Hoffm. Forked Spleenwort.
On rocks above the Waterfall, Hallaig, but very rare. New to V.C. 104.

ATHYRIUM.

*A. **Filix-fœmina** Roth. Lady Fern.
Common in suitable places with the var. *convexum* Newman.

SCOLOPENDRIUM.

*S. **vulgare** Sym. Hart's Tongue Fern.
Local in deep, rocky ravines; especially abundant in the gorges of the Arish Burn, Storab's Burn, Rudha na Leac, and on cliffs on Scalpay, and Rona.

CYSTOPTERIS.

*C. **fragilis** Bernh. Bladder Fern.
Locally common on rocks, more particularly on the conglomerate above Eyre.

POLYSTICHUM.

*P. **Lonchitis** Roth. Holly Fern.
Rare on limestone near the Waterfall, Hallaig, Raasay.

*P. **aculeatum** Roth. Prickly Shield Fern.
Rare in woodlands, Raasay, and Scalpay.

LASTREA.

*L. **montana** T. Moore. Sweet Mountain Fern.
Thinly distributed on the moorlands of all the islands.

*L. **Filix-mas** Presl. Male Fern.
Common in woods etc.; not seen on Rona.

*L. **spinulosa** Roth.
Sparingly, but generally distributed in shaded situations.

*L. **aristata** Rendle & Britten. Broad Shield Fern.
Not uncommon, but seemingly absent from Longay.

*L. **æmula** Brackenridge.
Shady woods between Brochel and Screapadal, Raasay, but only sparingly.

POLYPODIUM.

*P. **vulgare** L. Common Polypody.
Common on walls and rocks, everywhere.

PHEGOPTERIS.

P. **Dryopteris** Fée. Oak Fern.
Shady, wooded, and rocky places; rather local, but on all the islands save Fladday and Rona.

P. **Polypodioides** Fée. Beech Fern.
Not so plentiful, but scattered on all the islands.

OSMUNDA.

O. **regalis** L. Royal Fern.
Local in the ravines; Screapadal, Raasay, and Fladday; Allt Liath, Loch na Leoid, Allt Camas na Geadaig, and other points on Scalpay.

BOTRYCHIUM.

B. **Lunaria** Sw. Moonwort.
Common on the grassy slopes behind Oskaig Point, Raasay only.

EQUISETACEÆ.

EQUISETUM.

E. **maximum** Lam. Great Horse-tail.
Very rare, Brochel and Screapadal, Raasay.

E. **arvense** L. Common Horse-tail.
Very sparingly on the larger islands.

E. **sylvaticum** L. Wood Horse-tail.
Wet places, woods, roadsides etc.; fairly common on all the islands except Longay.

E. **palustre** L. Marsh Horse-tail.
Locally not uncommon; not on Longay.

E. **limosum** L. Smooth Horse-tail.
Local in lochs and pools.

LYCOPODIACEÆ.

LYCOPODIUM.

L. **Selago** L. Fir Clubmoss.
Not everywhere, but scattered in rocky places on all the moors; all islands.

L. **inundatum** L. Marsh Clubmoss.
Rare and local near the smaller lochs just west of the Brochel-Inverarish road; new to V.C. 104.

L. **annotinum** L. Interrupted Clubmoss.
Near Allt Liath, Scalpay only; new to V.C. 104.

L. **clavatum** L. Common Clubmoss.
Thinly scattered on rocky slopes west of Dun Caan, Raasay.

L. **alpinum** L. Alpine Clubmoss.
On high rocky moorlands; Dun Caan slopes, Raasay.

SELAGINELLACEÆ.

SELAGINELLA.

S. **selaginoides** Gray. Common Selaginella.
On Raasay, Scalpay, and Rona; damp bare soil.

ISOETES.

I. **lacustris** L. Quillwort.
Locally common in lochs on Raasay and Scalpay.

CHAROPHYTA.

CHARA.

C. **delicatula** Agardh. Stonewort.
Fearns, Raasay; with var. *annulata* Gr. and B.W.

C. fragilis Desv.
Pools; N. Raasay.
C. aspera Willd.
Oskaig, Loch Eadar da Bhaile, Hallaig, Raasay.
C. vulgaris L.
Loch Eadar da Bhaile, Raasay.

NITELLA.

N. translucens Agardh.
Raasay.
N. opaca Agardh.
Raasay.

(All the Characeæ, except *N. opaca,* seem to be new to V.C. 104.)

THE LEPIDOPTERA OF THE ISLE OF RAASAY AND OF THE ADJACENT ISLANDS OF SCALPAY, SOUTH RONA, FLADDAY, AND LONGAY.

BY J. W. HESLOP HARRISON, D.SC., F.R.S.

In 1935, as a result of the study of collections made by Dr. George Heslop Harrison in 1933, and by myself in 1934, I published a short paper (Scottish Naturalist, March and April 1935) dealing with the Lepidoptera of South Rona. Limited as the list was, it contained species so interesting from the zoogeographical standpoint that it was decided to work the other islands, Raasay, Scalpay, Fladday and Longay, as intensively as possible; the necessary researches were carried out during the summers of 1934-5-6. Moreover, in order to include the spring and autumn insects in our survey, my daughter, Miss Helena Heslop Harrison M. Sc., visited Raasay in September 1934, and my son in April, May, and June 1936. The present paper embodies the outcome of our joint labours.

As will be seen, three hundred and twenty nine species and many varieties are listed, and, as far as some of groups, like Rhopalocera and Geometers, are concerned, there can be little to add. However, in the case of the Noctuidae, owing to the general failure of sugar except on Scalpay, I anticipate that further discoveries will be made. Further, in the Microlepidoptera, in view of the obvious richness of the Fauna, it seems certain that the list will be more than doubled.

The nomenclature employed in the case of the Rhopalocera is that of the "*Generic Names of British Insects*" (Roy. Ent. Soc., Part 2, Feb. 1934). For the Microlepidoptera Meyrick's *Handbook* is followed whilst South's *Moths of the British Islands* (Series I and II) serves for the whole of the remaining groups.

NYMPHALIDAE.

Argynnis aglaia L.—One of the most abundant butterflies on the islands although not observed on Longay. It ascends from sea level, both on Raasay and Scalpay, to about 1000 feet; on Rona it occurs everywhere. In the latter island the dark female known as var. *scotica* prevails, and in some localities, as in the central area near the deserted village of Dry Harbour, it entirely replaces the type. On Raasay this form occurs sparingly in the Lewisian Gneiss area in the north, but fails progressively southward until in the Fearns—Eyre—Suisnish triangle only the type is found. In spite of the abundance of the insect on Scalpay, all the specimens captured were typical. Larvae, almost fullgrown, were collected on *Viola Riviniana* in April.

A. euphrosyne L.—Not plentiful, and in a form calling for no comment, in Central and Southern Raasay; apparently not previously recorded for any Hebridean island.

A. selene L.—Very abundant on Raasay and Scalpay in the small, brightly coloured, and heavily marked *insularum* form recently described by me; also new to the Hebrides.

Aglais urticae L.—Exceptionally common on all the islands of the group, including Longay and Fladday. In 1936 enormous masses of larvae occurred on the nettles around Brochel Castle; these displayed a very wide range of variation, very pale to very black forms being represented. The imagines, captured and bred, were a little more strongly marked than the usual English insects.

Nymphalis io L.—As has been reported elsewhere, a batch of larvae of this insect was observed on nettles under the cliffs near the Point of Eyre. This marks a great northward extension of range which emphasises the trend of recently reported movements of the species.

V. atalanta L.—Common on Raasay and Rona 1933-4-5-6, and rare on Scalpay in 1936. In general, although

Rona is the most northerly of the three islands, the insect was taken most freely there.

V. cardui L.—Sparingly on Rona and Raasay in 1933-34.

SATYRIDAE.

Eumenis semele L.—Rare in rocky places along the west coast of Raasay, a little more plentiful on the Conglomerates of northern Scalpay, but common generally on Rona. The Rona specimens, and those from Scalpay, were large and brightly coloured.

Maniola jurtina L.—In great numbers on all the islands except Longay; the var. *splendida* B.-W. forms the bulk of the populations.

Erebia aethiops Esp.—Also abounds on Raasay and Scalpay from sea level at Camas na Geadaig and Rudh'an Tarr Bhig, Scalpay, and South Fearns, Raasay, to the thousand foot level. Although its favoured haunts are generally located in sheltered spots on the moors, it may be found commonly in birch woods along Storab's Burn and Allt Brae, near Balachuirn, on the Arish Burn, and near Screapadal. It also flies freely in typical lowland marshes near Fearns and Scalpay House.

In general, its food plant is *Molinia caerulea,* but larvae have been swept from various *Festuca* and *Aira* species.

Little variation is observable amongst the imagines, although examples with extra ocelli may be taken.

Coenonympha tullia Müll.—This also is common and widely distributed on Rona, Raasay, Scalpay, and Fladday, often enough with the preceding insect, and similarly attached to *Molinia,* although in some localities it may utilise *Rynchospora alba* as a food plant. The var. *scotica* prevails.

C. pamphilus L.—Well distributed on all the islands and calling for no comment; often on the same ground as its congener.

LYCAENIDAE.

Callophrys rubi L.—Not rare at about 500 feet in southern Raasay, where it feeds on *Vaccinium Myrtillus,* and in central Scalpay, where it depends upon *Calluna vulgaris* and *Empetrum nigrum*. The imagines are quite typical, but the larvae are much more striking creatures than either continental or northern English specimens owing to the strength of the oblique markings.

Polyommatus icarus Rott.—Common throughout Rona, on Raasay from sea level to 800 feet, on Scalpay only along the Allt Camas na Geadaig, and sparingly on Fladday. The examples examined were large, and the females belonged to the var. *caerulea.*

PIERIDAE.

Pieris napi L.—Common on all the islands, with the larvae feeding on *Cardamine pratensis, C. flexuosa* and *C. hirsuta*. The females are darker than southern English examples, and both sexes are quite yellow on the lower side.

P. rapae L.—Very rare, observed at *Buddleia variabilis* flowers in Raasay House gardens, and on Scalpay in the extreme south.

P. brassicae L.—Casually in the north of Scalpay, and on Raasay near Inverarish and Brochel in 1934.

SPHINGIDAE.

Smerinthus populi L.—Common in the larval condition on *Populus tremula* and *Salix aurita*; on cliffs and moorlands.

NOTODONTIDAE.

Cerura furcula L.—Not common; ova and larvae taken from *Salix aurita* on Rona and Raasay. The insects reared were perfectly ordinary specimens.

Dicranura vinula L.—On the same plants as *S. populi* and common on all the islands. Although the imagines and larvae call for no comment, totally white eggs were collected from sallow on the moors above Holoman.

Pheosia tremula Cl.—Not plentiful, but well distributed.

P. dictaeoides Esp.—Larvae on birch, but imagines at light; on every island.

Notodonta ziczac L.—Eggs and larvae everywhere common on sallow and aspen. The larvae collected from aspen are often of a dark slate colour.

N. dromedarius L.—Common throughout the island group; generally taken as larvae or ova on birch or alder, but imagines on birch along the Allt Brae. The latter belong to the var. *perfusca* Stphs.

Lophoteryx camelina L.—Abundant everywhere.

Phalera bucephala L.—Larvae and ova on birch, sallow and rose; rare near Dry Harbour, Rona, and Screapadal, Raasay.

Pygaera pigra Hufn.—In spite of South's and Meyrick's remarks, this insect is restricted to *Salix aurita* on these islands, even in *S. repens* areas; it occurs rarely on Rona, not uncommonly along the south and east coasts of Raasay, and abundantly on Scalpay and Longay. The larvae apparently prefer to feed in the rain, when they may be seen out of their tents in hundreds in the favoured Scalpay habitats.

THYATIRIDAE.

Thyatira batis L.—Rare near Inverarish, Raasay.

Palimpsestis or F.—Swarms as larvae on aspens on the cliffs, both inland and along the coast; found on all the islands.

P. duplaris L.—Common on birch, Raasay only.

Polyploca flavicornis L.—Common as the var. *scotica* everywhere on the islands.

LYMANTRIIDAE.

Orgyia antiqua L.—Found along the Arish Burn and its tributaries, on Raasay only. In general, the larvae are quite typical, but in some the red colour is replaced by white, and the anterior and lateral hair pencils are less than one third their usual length. In fact, these larvae closely approximate those of the British Columbian *O. badia,* and would pass unchallenged in a series of larvae of that species.

LASIOCAMPIDAE.

Poecilocampa populi L.—Larvae from alder; Raasay only.

Lasiocampa quercus L.—The var. *callunae* Palmer alone occurs, but it swarms everywhere on the moorlands of all the islands.

Macrothylacia rubi L.—Common on the moors and elsewhere as larvae.

Cosmotriche potatoria L.—Ova, larvae, pupae and imagines taken on Raasay and Scalpay where the insect seems restricted to *Molinia*; these captures indicate a considerable northward extension of its range.

SATURNIIDAE.

Saturnia pavonia L.—Everywhere plentiful; larvae on *Calluna, Erica, Salix, Spiraea* etc.

DREPANIDAE.

Drepana falcataria L.—Sparingly, but generally, spread over the islands; imagines paler than our forms.

D. lacertinaria L.—On all the islands, and very much more plentiful than its ally.

CHLOEPHORIDAE.

Hylophila prasinana L.—Rare on birch and oak in S.W. Raasay.

ARCTIIDAE.

Spilosoma menthastri Esp.—Larvae and imagines, the latter of the buff form, found on Raasay only.

S. lubricipeda L.—Also taken as larvae and imagines near Fearns and Inverarish, Raasay.

Phragmatobia fuliginosa L.—Occurs commonly enough as var. *borealis* on all the islands.

Parasemia plantaginis L.—Sparingly and typical on Raasay and Rona.

Diacrisia sanio L.—Rare on the moors, Raasay.

Arctia caja L.—Larvae on Raasay, Rona, and Scalpay, and imagines on the first named island.

Hipocrita jacobaeae L.—Very rare along the southwest coast of Raasay; this marks an extension of its known range.

NOCTUIDAE.

Demas coryli L.—Quite common on all the islands; larvae chiefly on birch, but also on hazel.

Acronycta menyanthidis View.—Larvae on heather, sallow, *Myrica Gale*, etc. Most of the imagines are of the *scotica* Tutt facies, but a single totally black specimen was observed on Scalpay; it may be known as ab. *nigra* mihi.

A. euphorbiae Fab.—The larvae of this species may be found commonly and widely spread on Rona and Fladday, but on Raasay it is confined to the Lewisian in the north; not discovered on Scalpay.

A. rumicis L.—Typical forms, with the melanic var. *salicis* Curtis, may be obtained on all the islands.

Agrotis cursoria Hufn.—Rare on ragwort flowers near Suisnish, Raasay.

A. nigricans L.—Of casual occurrence with the preceding; Suisnish, Raasay.

A. tritici L.—Also very rare; Raasay only.

A. ypsilon Rott.—A single male at sugar, Camas na Geadaig, Scalpay.

Lycophotia strigula Thbg.—Everywhere common on the moors; typical forms and others approaching var. *suffusa* Tutt occur.

Exarnis augur Fab.—Not very common at ragwort on Raasay.

Euretagrotis agathina Dup.—Not uncommon on the moors on Raasay.

Noctua glareosa Esp.—Type and var. *rosea* Tutt beaten out of heather on Raasay.

N. castanea Esp.—A few taken from flowers on Raasay represent the type and var. *laevis* Haw.

N. baja Fab.— Rare on Raasay; frequents ragwort flowers in August.

N. brunnea Fab.—Larvae quite rare on low plants in Raasay House Woods.

N. primulae Esp.—The type is not very common, but vars. *subrufa* Haw. and *mendica* F. are a little more plentiful; beaten from *Calluna* by day.

N. *depuncta* L.—Very rare, Raasay.

N. *dahlii* Hb.—Type and var. *rufa* Tutt at *Erica* flowers; Raasay.

N. *xanthographa* Fab.—Larvae and imagines are abundant everywhere on Raasay, Scalpay, and Rona. The var. *rufa* Tutt predominates, but the type and var. *obscura* Tutt are common enough.

Triphaena comes Hb.—Common on Rona, Raasay, and Scalpay. Larvae taken from various plants, and imagines obtained at sugar, ragwort, heath, and woodsage; likewise beaten by day from heather and birch. Both larvae and imagines are extremely variable ,the former sometimes appearing a unicolorous black and ranging from that to the ordinary English form. On Scalpay, a large number of imagines were taken at sugar; amongst these vars. *adsequa* Tr., *grisea* Tutt, *ochrea* Tutt, *rufo-grisea* Tutt were noted. On the other hand, on Rona and Raasay, whilst the same forms occurred, at least 60% of the insects captured appertained to the vars. *rufa* Tutt, *curtisii* Newm., *nigrescens* Tutt, and *rufo-nigrescens* Tutt, with an even greater percentage of black forms on Rona. The var. *consequa* Hb. was bred from Raasay ova.

T. orbona Hufn.—A single specimen bred from a Raasay larva.

T. pronuba L.—The form taken on Raasay, Rona and Scalpay included the type, var. *ochrea* Tutt, var. *rufa* Tutt, var. *brunnea* Tutt and var. *ochrea-innuba* Tutt. A curious teratological specimen of the var. *brunnea* was taken from ragwort on Raasay; it shows extraordinary indentations in the wings.

T. ianthina Esp.—Of this series Tutt remarks "This species varies but little in any direction." With this, on the basis of the Raasay and Rona specimens, I cannot agree, for blackish, greenish, reddish, brown, and dark purple forms are exceedingly plentiful. These I hope to discuss in a future paper on the genetics of the genus.

Barathra brassicae L.—Anything but common on Raasay and Rona.

Mamestra oleracea L.—Larvae abundant on various low plants on Rona; it must, however, occur on Raasay as we have taken it on Eigg and Canna.

M. contigua Vill.—Sparingly on Raasay.

M. pisi L.—Common everywhere on bracken, thistle etc. on Raasay, Rona, Scalpay, Longay, and Fladday. Vars. *scotica* St., and *splendens* St. comprise the majority of the population, but a form between *distincta* and *suffusa* occurs on Raasay and Scalpay.

Dianthoecia nana Rott.—As the food plants, except for *Lychnis flos-cuculi*, are very local on these islands, this insect is quite rare. On Rona it occurs on the plant just named, at Oskaig it is found on *Silene maritima*, at Fearns on *Lychnis diurna*, and at Hallaig on *Silene acaulis*. The latter food plant is especially noteworthy.

D. capsincola Hb.—Very rare, at N. Fearns, Raasay, only.

Charaeas graminis L.—Extremely common on ragwort and scabious; on all the islands with var. *obsoleta* Tutt.

Bombycia viminalis F.—Along the Arish Burn, Raasay only; quite typical.

Luperina testacea L.—In grassy places on the edges of the woods near Raasay House.

Celaena haworthii Curt.—On Raasay, Rona, and Scalpay on the moors, but not really plentiful. Forms approaching var. *hibernica* St. may be taken.

Apamea basilinea F.—Imagines captured in and about buildings on the three larger islands.

A. secalis L.—Very common at ragwort and rush flowers; practically the whole range of British variation may be observed in the specimens. Found on all the islands.

Miana strigilis L.—In order to study the *M. strigilis* complex, as represented in the islands, preparations were made of the genitalia of all the specimens captured in 1935-6; these were examined in the light of recent work by Heydemann ("Zur Morphologie und Formenbildung der Gattung *Miana* Steph. I.

Die *Miana strigilis* L.-Gruppe" Ent. Zeit. Bd. XXXXVI. 1932 No 2,3,5,7,) and Wolff. ("Revision af Danske Sommerfuglearter omtalt i 'Danmarks Fauna' " Entom. Meddel. Bd. XIX. Hefte 5, 1935). From my investigation it appears that both of the species reinstated by these authors, *M. versicolor* Bkh. and *M. latruncula* Hbn., are included in our collections.

Of *M. strigilis* proper, the majority of the specimens (captured at rush-flowers) belongs to the type form, but small percentages of insects referable to var. *ferrea* Warr., *suffumata* Warr., and *æthiops* Heyd. occur; the species occurs on all the islands.

M. versicolor Bkh.—Three specimens only, approximating var. *pseudolatruncula* Heyd., were taken near Inverarish, Raasay.

M. latruncula Hbn.—Typical forms, and others representing var. *unicolor* Tutt and var. *aethiops* Haw. were encountered not unfrequently on Rona and Raasay, whilst types were taken sparingly on Scalpay. Forms serving to link var. *unicolor* with typical *latruncula* are of somewhat free occurrence.

M. fasciuncula Haw.—Plentiful on ragwort and rush flowers along the coasts of Raasay, Rona, and Scalpay, with vars. *cana* Stgr. and *pallida* Tutt occurring not infrequently.

M. bicoloria Vill.—Scarce and local in Raasay; var. *rufuncula* Haw. also appears in the collections. These captures mark a northward extension of the known range of the insect, but it appears certain as in the case of *Taeniocampa gracilis* etc. that it will turn up on other islands.

M. literosa Haw.—Very rare at sugar in Raasay House Woods.

Xylophasia rurea L.—Common, and of general occurrence, in the islands. The varieties *ochrea* Tutt, *flavo-rufa* Tutt, *putris* Hb., *combusta* Haw., and *nigro-rubida* Tutt are all to be found freely.

X. monoglypha Hufn.—Also plentiful at sugar and on flowers. On Scalpay only more or less typical forms linked to var. *obscura* are to be taken, but on Raasay and Rona vars. *brunnea* Tutt, *infuscata* B.-W., and *aethiops* Stgr. are not scarce. Very few examples, however, are referable to the extreme var. *aethiops*.

Aporophylla lutulenta Bkh.—Not very common on Raasay between Clachan and Inverarish. Types and var. *luneburgensis* Fr. both occur.

A. nigra Haw.—Very rare in the woods along the Arish.

Dasypolia templi Thnbg.—At sallows near Balachuirn; only the var. *ochracea* Tutt was observed. The food plant on Raasay cannot be *Heracleum Sphondylium*, for that is a rare plant which does not grow in the Balachuirn area. In all probability *Angelica sylvestris* is utilised.

Polia chi L.—Quite rare on Raasay; only white specimens observed.

Phlogophora meticulosa L.—Local in Raasay House woods.

Euplexia lucipara L.—Not uncommon and well distributed.

Hydroecia micacea Esp.—Very common at ragwort flowers; typical examples, as well as vars. *grisea* Tutt and *brunnea* Tutt, were captured.

H. crinanensis Burrows.—This species is much more abundant than any of the other three segregates of the old *H. nictitans* complex, both on Raasay, Scalpay, and Rona; in fact, genuine *H. nictitans* has never come under observation. The whole *crinanensis* range of variation occurs.

H. paludis Tutt.—Only a very small percentage of the *Hydroeciae* taken from ragwort and other flowers belong to this species, although it may be captured on all the islands; just as variable as the preceding species.

H. lucens Fr.—Everywhere common and very variable. It should be noted that the determinations of this species and its allies were made from a long series of preparations of genitalia derived from insects captured in 1935-36.

Leucania pallens L.—Not of free occurrence on Scalpay and Raasay, and usually observed at rush flowers.

Stilbia anomala Hw.—Not at all rare on Rona near the cave and Dry Harbour; the females are quite black in some cases.

Caradrina quadripunctata F.—Swarming everywhere on ragwort flowers at dusk; also captured in numbers as it hid indoors by day.

Amphipyra tragopogonis L.—Rare in the south of Raasay.

Panolis griseovariegata Gze.—Larvae on *Pinus sylvestris* and *Larix decidua*, and imagines at flowers of *Salix aurita*; along the Arish Burn, Raasay, only.

Pachnobia rubricosa Fab.—Contrary to my usual experience with specimens from Scottish localities, Raasay series of this species show a preponderance of *pallida* and *rufa* forms with a sprinkling of *mucida* representatives. None of the extreme grey forms were taken. These observations apply to series from Balachuirn, Oskaig, Inverarish, and Fearns.

Taeniocampa gothica L.—Here again we deal with a species common on Raasay, Scalpay, and Rona in which the usual Scottish range of variation is not exhibited. Most of the specimens studied would be classified under var. *pallida* Tutt and var. *rufescens* Tutt. No *obsoleta* forms were captured, although they do occur on other islands of the Inner Hebrides, as on Eigg.

T. stabilis View.—Also very common; the type, and vars. *pallida* Tutt, *suffusa* Tutt and *rufa* Tutt, are all plentiful.

T. incerta Hufn.—Plentiful; the bulk of the specimens belong to var. *nebulosus* Haw. although most of the usual pale forms may be taken.

T. gracilis Fab.—This, I believe, is the first Hebridean record for this species; it, however, is far from uncommon in the Balachuirn, Holoman, and Brae areas on Raasay. The vars. *pallida* St., and *rosea* Tutt also occur. Localities for it were also detected on Eigg.

Omphaloscelis lunosa Haw.—This insect likewise is now reported for the first time from the Hebrides, and, as in the case of *T. gracilis* also represents a northward extension of its known range. Var. *obsoleta* Tutt and the type were taken in S.W. Raasay, as well as on Canna and Eigg.

Xanthia lutea Strm.—Sparingly on Rona and Raasay.

X. fulvago L.—Very rare, Balachuirn and Inverarish, Raasay.

Calocampa exoleta L.—Common at sallow blossom on Raasay.

C. vetusta Hb.—Even more plentiful than the allied species; imagines at sallow generally, and larvae near Brochel.

Anarta myrtilli L.—Very common on Raasay, Rona, and Scalpay.

A. melanopa Thbg.—A single specimen on the western slopes of Dun Caan, Raasay, in May 1936.

Prothymnia viridaria Cl.—Abounds with the var. *fusca* Tutt on all the Raasay moors.

Plusia chrysitis L.—Extremely rare and, up to the present, only captured near the Post Office, Raasay.

P. interrogationis L.—Common on all the moorlands of the various islands.

P. gamma L.—As elsewhere an immigrant, but larvae, pupae, and imagines occurred on Rona and Raasay in 1936.

P. iota L.—Also unexpectedly rare and only seen near Dry Harbour, Rona.

Abrostola tripartita Hufn.—Abundant on Camas na Geadaig, Scalpay, Brochel, Screapadal, Clachan, Raasay and generally on Rona.

Hypena proboscidalis L.—Abundant on all the islands wherever nettles grow.

GEOMETRIDAE.

Geometra papilionaria L.—Not really common, but ova, larvae, and imagines were taken on all the islands visited.

Pylarge fumata L.—On the moors near Oskaig, Raasay only; the specimens were exceedingly heavily marked.

Ephyra pendularia Cl.—Larvae beaten in small numbers from birch at Screapadal, Brae, and along the Arish, Raasay.

Ortholitha limitata Scop.—Local and uncommon, Point of Eyre, Raasay and Rona; on both islands the prevalent form is of a bright yellow.

Anaitis plagiata L.—Fairly common, Hallaig, Fearns, and Clachan, Raasay; also widespread on Rona.

Carsia paludata Thnbg.—Very abundant on Rona, and scarce and local on Raasay; the var. *imbutata* Hb. alone occurs.

Trichopteryx carpinata Bkh.—Sparingly in the birch woods on Raasay; the var. *fasciata* Prout is also encountered.

Cheimatobia brumata L.—Not common in the Raasay House Woods.

C. boreata Hb.—Uncommon as larvae on birch on Raasay.

Oporinia nebulata Thnbg.—Not at all common in forms between the type and *pallida* Prout; Raasay only.

O. christyi Prout.—Larvae sparingly on wych elm along the Arish Burn, Raasay.

O. autumnata Bkh.—Larvae common on birch and alder; the vars. *intermedia* Clark and *sandbergi* Lampa occur as well as the type.

O. filigrammaria H.-S.—Scarce in sheltered places on the moors of Raasay.

Lygris testata L.—Plentiful on Raasay, Rona, and Scalpay; varies towards var. *fuscata* Meves and *insulicola* Stgr.

L. populata L.—Not so common as *L. testata*, but still widespread; variation not great.

Cidaria pyraliata Schiff.—Rare, on Raasay only.

C. fulvata Först.—Larvae and imagines from *Rosa glabrata* etc. on Rona, from *Rosa Sherardi* on Raasay, and from *Rosa spinosissima* on Scalpay; rather local.

C. corylata Thnbg.—Common on all the islands, including Longay.

C. truncata Hufn.—Very abundant in one long-drawn out brood in July and August; observed everywhere, including the islands of Longay and Fladday; all the usual varieties, except *comma-notata* Haw. and *perfuscata* Haw., may be taken.

C. concinnata Stphs.—Forms which can only be referred to this species may be captured on Rona and Raasay.

C. immanata Haw.—Just as abundant and widely spread as *C. truncata*, and equally variable.

C. siterata Hufn.—Rather rare on Raasay.

C. miata L.—Plentiful everywhere.

Thera variata Schiff.—Very rare amongst spruces near the stone bridge across the Arish Burn.

T. obeliscata Hb.—Common and quite typical on Raasay, Rona, and Scalpay.

T. firmata Hb.—Rare in Raasay House Woods.

T. cognata Thnbg.—Found sparingly on Rona and Scalpay; repeated searches on Raasay, both on *Juniperus communis* and *J. sibirica*, have proved fruitless. The form *griseata* Fuchs, as well as the darker and more purple forms, occur.

T. juniperata L.—Noted in the form of the var. *scotica* on Rona and Scalpay; fails in Raasay.

Lampropteryx suffumata Schiff.—Not common on *Galium saxatile* on Raasay.

Coremia munitata L.—Very rare on Raasay.

C. ferrugata Cl.—Single brooded, and only taken on Raasay between Arish and Oskaig; also the var. *salicaria* Haw.

C. designata Hufn.—Not very common in the west of Rona and Raasay.

Amoebe olivata Schiff.—Sparingly on Rona and Scalpay, but in enormous quantities in certain Raasay localities. I once counted fifty-five as they flew from a small rock in the Filmy Fern ravine which strikes off at right angles to the Arish Burn. In that ravine, thousands may be disturbed any day in August. It also frequents ragwort flowers in the evening.

A. viridaria Fb.—Thinly scattered over all the islands, and never in the quantities of its relative.

Malenydris salicata Hb.—Rare along the Storab and other burns on Raasay.

M. multistrigaria Haw.—Common enough at all suitable stations on the moors and in the woods, Raasay, coming freely to sallow blossom; larvae swept on Allt Liath, Scalpay.

M. didymata L.—This species is not uncommon on all the islands, and seems very variable. The form *hethlandica* is found, but no names seem available for many of the most striking varieties. The variation seems worthy of special and sustained attention.

Venusia cambrica Curt.—Not uncommon along the more heavily wooded burn sides on Raasay.

Entephria caesiata Schiff.—Unexpectedly scarce, and only seen on Raasay, where it varies but little.

Xanthorhoe montanata Schiff.—Not at all plentiful, Raasay and Rona.

X. fluctuata L.—Also rarely observed, Raasay.

Epirrhoe sociata Bork.—Fairly common; both larvae and imagines encountered. Most of the latter represent var. *obscurata* South.

E. tristata L.—Not very common, with some of the specimens mimicking the var. *obscurata* of the preceding species; these may be known as var. *cognata* mihi.

Eulype hastata L.—Excessively abundant, and feeding exclusively on *Myrica Gale*, on every one of the islands; examples referable to *subhastata* Nolcken were obtained on Rona and Longay.

Mesoleuca ocellata L.—Taken at Rudha na Leac and Holoman, Raasay, and on Rona.

M. bicolorata Hufn.—Common wherever alders grow, but always more or less typical.

Perizoma alchemillata L.—Only along the edge of the shingle near Eyre Lighthouse, Raasay, but there plentiful; larvae on *Galeopsis Tetrahit* and *G. speciosa*.

P. albulata Schiff.—Abundant on Raasay, but rare on Rona; var. *griseata* Stgr. and var. *niveata* Stph. occur.

P. bifasciata Haw.—On Red Bartsia near N. Fearns, Raasay.

P. minorata Tr.—Rare and local, Raasay.

P. blandiata Schiff.—Also of sparse occurrence, Raasay.

Camptogramma bilineata L.—Very common on all the islands. The var. *infuscata* Gmpbg. occurs freely, but many of the specimens should be assigned to var. *atlantica* Stgr.

Hydromena furcata Thnbg.—Really scarce, and beaten out of sallow, hazel, and, more rarely, from *Vaccinium*; also taken at ragwort flowers. Forms *sordidata* Fab. and *obliterata* Prout at Balachuirn and along the Arish; var. *fusco-undulata* Don. on the hill behind the church.

H. impluviata Hb.—Common enough wherever alder grows.

H. ruberata Fr.—Apparently restricted to *Salix aurita*, but common everywhere on that shrub, even on Longay.

Anticlea badiata Hb.—Larvae on various roses of the *Sherardi* group, Rona and Raasay.

A. nigrofasciaria Gze.—With the last named species, but much less freely.

Eupithecia oblongata Thnbg.—Larvae rather rare on ragwort near Suisnish Point, Raasay.

E. pulchellata Stph.—Larvae on *Digitalis purpurea* on Rona, Raasay, and Scalpay; imagines of the *hebudium* Sheld. form.

E. venosata Fab.—Larvae on the unusual foodplant *Silene acaulis* on the cliffs between Screapadal and Hallaig, Raasay.

E. distinctaria H.-S.—A single larvae from thyme on the geyser vent behind Brochel, Raasay.

E. absinthiata Cl.—Larvae on ragwort etc. between Suisnish and Inverarish, Raasay.

E. goosensiata Mab.—Larvae from heather on all the islands, including Longay.

E. vulgata Haw.—Along the Arish Burn, Raasay.

E. castigata Hb.—Common on all the islands.

E. lariciata Fr.—Common on larches in Raasay House grounds.

E. helveticata Bdv.—Larvae abundant on *Juniperus sibirica* on Scalpay and Rona, in the former case at 1000 feet above sea level. Curiously enough, like the other juniper feeders, absent from Raasay, in spite of the presence of the food plant.

E. satyrata Hb.—Generally distributed on all the islands.

E. tenuiata Hb.—Imagines at ragwort near Inverarish, where the food is clearly *Salix aurita*.

E. nanata Hb.—In large numbers on the moorlands everywhere.

E. exiguata Hb.—Not plentiful in Raasay House Woods.

Pelurga comitata L.—A single specimen, Clachan, Raasay.

Coenocalpe vittata Bkh.—Quite rare on Rona and Raasay.

Abraxas grossulariata L.—This insect swarms in every valley on Raasay, sometimes, as on the escarpment south of Dun Caan, in inconceivable numbers. We once counted 93 drowned in a pool about a yard square at that point. On Scalpay, it is equally abundant, generally at elevations of 800-1000 feet above sea level. It only occurs sparingly on Longay, and seems absent from Rona. In all cases the food plant is *Calluna vulgaris*.

Notwithstanding its great abundance, the variation observed was trifling, although the occurrence of var. *lacticolor* on Raasay is very noteworthy.

Lomaspilis marginata L.—Common generally, wherever *Salix aurita* grows in sheltered positions.

Cabera pusaria L.—Abundant on all the islands.

C. exanthemata Scop.—Like the preceding species.

Ellopia prosapiaria L.—Larvae on pine near the church, Raasay.

Metrocampa margaritaria L.—Very common amongst birches and widely distributed.

Selenia bilunaria Esp.—Common as larvae on birch at Inverarish, Brae, Brochel, and Screapadal, Raasay. The var. *infuscata* Strand may be found, but some of the forms are strongly peppered with black above and heavily marked below. These varieties I call var. *insulicola*.

S. lunaria Schiff.—Also not rare in the same habitats on Raasay.

Gonodontis bidentata Cl.—Abundant on every island, generally on birch but sometimes on larch. Whenever these trees bear lichen-clad twigs magnificently variegated black and light green larvae may be beaten.

Crocallis elinguaria L.—Rare on Rona and Raasay, feeds on heather.

Himera pennaria L.—Larvae common on birch, Raasay only.

Opisthograptis luteolata L.—Larvae abundant on mountain ash and birch; ascends high up the hills *via* the mountain ashes in the ravines.

Venilia maculata L.—An interesting species new to the Hebrides, and far from rare at various points in western Raasay; feeds on wood-sage.

Hybernia marginaria Hb.—Larvae quite common on birch on Raasay.

H. defoliaria Cl.—Sparingly on oak in Raasay House Woods.

Phigalia pedaria Fab.—Common enough on birch and oak in the woods between the Post Office and Inverarish, Raasay.

Nyssia zonaria Schiff.—Larvae swept on Scalpay only; an interesting capture although the insect has been recorded for Skye, Coll, S. Uist and Barra.

Amphidasys betularia L.—Very common everywhere on birch on Raasay and Scalpay, but rarer on Rona. Most of the specimens reared were quite typical, but one had a black body and another almost black wings, sprinkled with white scales.

Boarmia repandata L.—Common on birch on Rona, Raasay, and Scalpay; easily startled by day, and also netted from ragwort flowers in the evening. Most specimens belonged to var. *sodorensium* Weir.

Tephrosia bistortata Gze.—Sparingly on birch along the Arish Burn, but common on birch and *Salix Caprea* near Brae and Balachuirn. The imagines were a little less heavily barred than the average Scottish or North of England form, but still were strikingly different from southern specimens. Many of the larvae beaten were quite unrecognisable at first sight as those of *T. bistortata.* Some from sallow were unicolorous pale grey, and others, from lichen-clad birches, not unlike the *G. bidentata* mentioned above.

Gnophos obscurata Schiff.—One on the cliff along the Allt Brae, Raasay.

G. myrtillata Thnbg.—Larvae from *Erica* on Raasay moors.

Ematurga atomaria L.—In great numbers on every island.

Bupalus piniaria L.—Common amongst Scots pine on Raasay, Rona, and Scalpay.

ZYGAENIDAE.

Zygaena filipendulae L.—Common on Raasay along the sea coast at Fearns and Eyre, but striking inland at S. Fearns, on the moors behind Inverarish and Manish, and on the Conglomerate in Northern Scalpay. In these islands the species emerges eight weeks earlier than it does in Durham or in Fifeshire.

Z. achilleae Gn.—This species was first discovered on the lower southward slopes of Beinn na Leac where they are covered with a mixed growth of *Lotus corniculatus, Thymus Serpyllum, Erica cinerea, Calluna vulgaris, Hypericum Androsaemum* etc. Cocoons were collected from the rocks, but no imagines could be found. However, careful dissection of dead pupae revealed that the species represented was *Z. achilleae.* It seems noteworthy that the extracted imagines resembles Oban examples much more closely than the two hopelessly worn specimens captured later. Like *Z. filipendulae* this species emerges very early.

SESIIDAE.

Sesia muscaeformis View.—Rarely on the *Armeria maritima* on the rocks of Holoman Island; this marks a large extension of its range in the west of Great Britain.

HEPIALIDAE.

Hepialus humuli L.—Behind Oskaig Point, Raasay.

H. sylvinus L.—Rare on Raasay along the Brochel Road.

H. fusconebulosus De G.—Not uncommon amongst *Pteris* on Raasay, Rona, and Scalpay.

H. hectus L.—Sparingly on Rona and Raasay.

H. lupulinus L.—Rare on Rona.

GALLERIADAE.

Aphomia sociella L.—Common on the tree trunks in eastern Raasay, also on Scalpay.

Galleria mellonella L.—Rare near Inverarish, Raasay; apparently new to Scotland.

CRAMBIDAE.

Crambus pascuellus L.—Widespread on all the islands.

C. ericellus Hb.—On the slopes of Dun Caan, Raasay.

C. pratellus L.—Common on Raasay and Scalpay.

C. culmellus L.—Raasay and Rona, plentiful.

C. hortuellus Hb.—Beinn Loch a Mhuilinn, Scalpay.

C. pinellus L.—Raasay and Rona.

C. margaritellus Hb.—General but not common.

PYRAUSTIDAE.

Hydrocampa nymphaeata L.—Very common, Loch Eadar da Bhaile, Loch a Mhuilinn, Loch an Uachdair, Raasay, and Loch Braig, Rona.

Phlyctaenia lutealis Hb.—Swarming everywhere.

Pyrausta purpuralis L.—Not uncommon, Raasay.

P. aurata Sc.—Not uncommon, Raasay, where its food plant is probably *Thymus*.

P. caespitalis Schiff.—Rare on Raasay and Rona.

Scoparia ambigualis Tr.—Common on all the islands.

Mesographe forficalis L.—Fairly common everywhere.

PTEROPHORIDAE.

Platyptilia cosmodactyla Hb.—Not common, Raasay.

P. acanthodactyla Hb.—Not common, Raasay.

P. bertrami Rsl.—Scarce on Raasay; this seems to be a new record for Scotland.

Stenoptilia bipunctidactyla Hw.—Common enough on Raasay, Rona, and Scalpay.

EPIBLEMIDAE.

Eucosma dimidiana Sodof.—Common on all the islands.
E. sauciana Hb.—Raasay, along the upper road.
E. arbutella L.—Rare near Loch Storab, Raasay.
E. lacunana Dup.—Plentiful and widespread, on all the islands.
Enarmonica vacciniana Z.—Rather rare, Raasay.
Ancylis myrtillana Tr.—Rare, Raasay.
A. siculana Hb.—Raasay and Scalpay.
Cydia ramella L.—All the islands, but not common.
C. fractifasciana Hw.—Widespread on the islands; new to Scotland.
Epiblema tripunctana F.—Raasay, Scalpay.
E. penkleriana F.R.—Raasay, Rona, Scalpay.
E. similana Hb.—Raasay.
E. pflugiana Hw.—Common generally.
E. ophthalmicana Hb.—N. Raasay, Longay, Scalpay but rare; apparently a new Scottish record.
E. solandriana L.—Common on all the islands.
Hemimene plumbagana Tr.—Abundant everywhere.
Lipoptycha plumbana Sc.—Common, Raasay.
Pammene argyrana Hb.—Rare near Inverarish, Raasay.

TORTRICIDAE.

Rhacodia caudana F.—Generally distributed.
Acalla hastiana L.—Common and on every island.
A. rufana Schiff.—Rona and Raasay.
A. niveana F.—Rare, Balachuirn, Raasay.
A. ferrugana Tr.—Common, Raasay; rather rare, Rona.
A. aspersana Hb.—Generally distributed.
Philedone gerningana Schiff.—Sparingly on Raasay.
Cacoecia podana Sc.—Common on Raasay.
C. musculana Hb.—Raasay, not common.
Pandemis ribeana Hb.—Raasay and Scalpay.
Tortrix bergmanniana L.—Common everywhere.
T. ministrana L.—Also plentiful everywhere.
T. incertana Tr.—Rare, Raasay.
T. bellana Curt.—Rona, near the cave, rare.
T. osseana Sc.—Common and general.

PHALONIADAE.

Phalonia cnicana Dbld.—Not common, Scalpay.
P. ciliella Hb.—Common, Raasay.

GELECHIADAE.

Gelechia terrella Hb.—Common everywhere.
G. proximella Hb.—Raasay, Scalpay.
G. diffinis Hw.—Raasay House Woods.
G. ericetella Hb.—Plentiful generally.
Chelaria huebnerella Don.—Rather rare, Raasay; a new Scottish record apparently.

OECOPHORIDAE.

Semioscopis steinkellneriana Schiff.—Along the Arish, Raasay.
Depressaria costosa Hw.—Fearns, Raasay.
D. arenella Schiff.—Common as larvae, Raasay, Scalpay.
D. ciliella St.—Rare near Brochel, Raasay; new to the Scottish lists.
D. applana F.—Common on Raasay, and Scalpay.
D. nervosa Hw.—Common Oskaig, Raasay, and in the marsh near Scalpay House.
Acompsia pseudospretella St.—Inverarish, Raasay.

ELACHISTIDAE.

Coleophora viminetella Z.—Common, all islands.
C. fuscedinella Z.—Raasay only; a new Scottish record.
C. limosipennella Dup.—Common and well distributed.
C. laricella Hb.—Raasay, rare.
C. discordella Z.—Scalpay and Raasay.
C. caespititiella Z.—Abundant everywhere.
Epermenia chaerophyllella Gze.—Sparingly, Raasay.

PLUTELLIDAE.

Cerostoma xylostella L.—Raasay, not uncommon, and seemingly new to Scotland.
Plutella cruciferarum Z.—S. Scalpay only.
Glyphipteryx thrasonella Sc.—Common in most islands.
Simaethis fabriciana L.—Common on all the islands.

TINEIDAE.

Nepticula aucupariae Fr.—Raasay.
N. nylandriella Tgstr.—Raasay.
N. betulicola St.—Raasay.
Lithocolletis alnifoliella Dup.—Amongst alder, Raasay.
L. ulmifoliella Hb.—Scalpay and Raasay.
L. viminetorum St.—Scalpay and Raasay.
L. viminiella St.—Raasay.
L. scopariella Z.—Raasay, not common; new to Scotland.
L. emberizipennella Bch.—Raasay and Scalpay.
Ornix scoticella St.—Raasay only.
Gracilaria elongella L.—Common, Raasay and Scalpay.
G. tringipennella Z.—Raasay.
Tischeria complanella Hb.—Raasay House Woods.
Argyresthia brocheella Hb.—Raasay and Scalpay.
A. goedartella L.—Generally common.
A. conjugella Z.—Common, all the islands.
Swammerdamia heroldella Hb.—Scalpay and Raasay.
Fumea intermediella Br.—Rona near the cave, and Raasay near the reservoir.
Lampronia tenuicornis St.—Raasay; apparently the first Scottish record.
Tinea cloacella Hw.—Raasay.
T. fuscipunctella Hw.—Abundant in a deserted building N. Scalpay; new to Scotland.
Nemophora swammerdammella L.—Raasay only.

THE TRICHOPTERA OF THE ISLE OF RAASAY AND OF THE ADJACENT ISLANDS OF SOUTH RONA AND SCALPAY.

By J. W. Heslop Harrison D.Sc., F.R.S.

This list of species does not purport to be more than a preliminary account of the Caddis-flies found on the islands named above, for it is based on captures made more or less casually during the progress of the work on other insect groups, and on the Flora. It should, however, serve as a solid foundation for further studies.

The whole of the specimens available were taken by my son Dr. George Heslop Harrison and myself, and, with the exception of the later 1936 collections, which were examined by Mr. Martin E. Mosely, I am responsible for their determination.

RHYACOPHILIDAE.

Rhyacophila dorsalis Curt.—In the upper portions of the course of the Allt Liath, Scalpay, and in Storab's Burn and others below Dun Caan, Raasay.

Agapetus fuscipes Curt.—Along the Allt Brae, Raasay, and on Rona.

HYDROPTILIDAE.

Hydroptila forcipata Eaton.—Not uncommon on Loch na Mna, Raasay.

Oxyethira costalis Curt.—Loch Braig, Rona, pools just above Loch an Leoid, Scalpay, and Loch Eadar da Bhaile, Raasay.

PHILOPOTAMIDAE.

Philopotamus montanus Donov.—In abundance on the small loch south-west of Loch na Meilich, Raasay, and in Loch a Mhuilinn, Scalpay.

Wormaldia occipitalis Pict.—On several lochs near Carn nan Eun, Raasay.

POLYCENTROPIDAE.

Plectronemia conspersa Curt.—On the Arish Burn, Raasay.

Polycentropus kingi Mc L.—Only beneath the waterfall by means of which the Allt Liath leaves Loch an Leoid, but very plentiful there.

Holocentropus dubius Stph.—Loch Braig, Rona. Mosely named a single female from Loch an Leoid, Scalpay as *Holocentropus* sp. ; in all probability it belongs to this species.

Cyrnus trimaculatus Curt.—Loch Eadar da Bhaile, Raasay.

PSYCHOMYIDAE.

Tinodes waeneri L.—Loch Storab, Raasay.

PHRYGANEIDAE.

Phryganea varia Fab.—Common enough on Rona, Loch an Uachdair, Loch na Mna etc., Raasay, and Loch an Leoid, Scalpay.

P. striata L.—Small lochs near Crachan Lodge, Raasay.

P. obsoleta Hag.—In the same localities as *P. varia* and equally abundant.

Agrypnia picta Kol.—Loch Eadar da Bhaile and Loch a Chadarcharnaich, Raasay.

MOLANNIDAE.

Molanna palpata McL.—Near Balachuirn, Raasay, Loch Braig, Rona, and in several pools on Scalpay.

LEPTOCERIDAE.

Leptocerus nigronervosus Retz.—Abundant, Loch Eadar da Bhaile, Raasay.

L. aterrimus Stph.—Also plentiful in Loch Eadar, Raasay, and Loch Braig, Rona.

L. fulvus Ramb.—Rare, low-lying pools on Raasay.

L. cinereus Curt.—As with the preceding.

Mystacides azurea L.—In Loch na Bronn, Raasay.

Oecetis ochracea Curt.—Along the Arish Burn, Raasay.

ODONTOCERIDAE.

Odontocerus albicorne Scop.—In the more rapidly flowing portions of the Storab Burn, Raasay.

LIMNOPHILIDAE.

Colpotaulius incisus Curt.—Beaten from various shrubs in Raasay House Woods.

Limnophilus rhombicus L.—Beaten from alders on the Allt Brae, Raasay.

L. flavicornis Fab.—Common on Raasay.

L. marmoratus Curt.—Rona, Raasay, and Allt Liath, Scalpay.

L. lunatus Curt.—From alder and birch along the Arish; common.

L. centralis Curt.—On lochs and streams; abundant on all the islands.

L. stigma Curt.—Not common in the Oskaig area, Raasay.

L. affinis Curt.—Loch Eadar da Bhaile and the adjoining streams, Raasay.

L. auricula Curt.—Sparingly on Raasay.

L. griseus Curt.—Loch Storab, Raasay.

L. luridus Curt.—Loch Beag, N. Raasay.

L. sparsus Curt.—Common along most of the burns on Raasay and Scalpay.

Stenophylax stellatus Curt.—Common on the Allt Brae etc., Raasay, Allt Camas na Geadaig, Scalpay, and on Rona.

S. latipennis Curt.—On the mountain torrents near Loch na Mna, Raasay.

Micropterna sequax McL.—Near Holoman Island, Raasay.

M. lateralis Stph.—On the Arish Burn, Raasay.

Halesus radiatus Curt.—On the stream leading from Loch Eadar da Bhaile to the sea on Raasay.

Drusus annulatus Stph.—On the burn flowing into the sea just north of the cave on Rona.

Apatania wallengreni McL.—Quite abundant on the birches growing on the rocks near the Allt Liath waterfall, Scalpay.

SERICISTOMATIDAE.

Goera pilosa Fab.—General between Balachuirn and Inverarish, Raasay.

Crunoecia irroratus Mc L.—Quite common in the upper courses of the torrents on Scalpay and Raasay.

Lepidostoma hirtum Fab.—Near the outlet of Loch Eadar da Bhaile, Raasay, and there plentiful.

THE CECIDOMYIDAE OR GALL GNATS OF THE ISLE OF RAASAY AND OF THE ADJACENT ISLANDS OF SCALPAY, RONA, AND LONGAY.

By J. W. Heslop Harrison D.Sc., F.R.S.

Very little time could be assigned to the study of this group, and, as the paucity of the number of species will betray, little return was obtained for the time so spent. From these remarks it seems either that our labours were ill-directed, or that there were actually few species present; to the second of these two possibilities I incline. If asked for the reasons for my opinion, I would give (1) the scarcity, or absence, of many plants well known to support numbers of Cecidomyid species, (2) the prevalence of the same plant or plants (practically none of which bear Gall gnats) over large areas, and (3) the very exposed nature of the possible habitats. There seems to me, therefore, very little likelihood that very serious additions will be made to the present compilation.

Subfamily *CECIDOMYINAE*.

Group LASIOPTERARIÆ.

Clinorrhyncha millefolii Wachtl.—Found on the capitula and, in particular, in the achenes of *Achillea Millefolium* and *A. Ptarmica*; in the latter case there was often hypertrophy of the florets. Chiefly in southern and western Raasay.

Group OLIGOTROPHARIÆ.

Rhopalomyia millefolii H. Loew.—Sparingly on *Achillea Millefolium*; Balachuirn and Fearns, Raasay, also on Scalpay.

R. palearum K.—Very rare on *Achillea Ptarmica*, Eyre district, Raasay.

Misopatha ptarmicae Vall.—Common on the same plant as the preceding throughout Raasay, Rona, and Scalpay.

Arceuthomyia valerii Tav.—Sparingly, and like the rest of the juniper feeders not found on Raasay; confined to Rona, to the west of Loch Braig.

Semudobia betulae Winn.—On birch catkins, Inverarish and Balachuirn, Raasay.

Iteomyia capreae Winn.—On *Salix aurita* on Rona and Scalpay, and on the same species and *S. cinerea* on Raasay.

I. major K.—With the last species but distinctly rarer; found also on Longay.

Janetiella thymi K.—On *Thymus Serpyllum* but far from common; Raasay, Fearns to Eyre.

J. thymicola K.—Well distributed on thyme on Rona, Raasay, and Scalpay; a hoary gall, not glabrous like the allied form.

Mayetiola ventricola Rübs.—In a shuttle-shaped gall at the base of *Molinia* shoots; scattered on moorlands of Raasay and Scalpay.

Macrolabis luceti K.—On *Rosa glaucophylla* and *R. spinosissima* in the area between Allt Liath and Allt Camas na Geadaig, Scalpay, and widespread on roses of the Caninae group on Raasay.

Rhabdophaga albipennis H. Loew.—On sallow shoots, especially when well grown, Raasay only.

R. heterobia H. Loew.—On sallow shoots and catkins; Raasay near Inverarish.

R. marginemtorquens Winn.—On *Salix viminalis* near Dry Harbour, Rona.

R. nervorum K.—Not uncommon locally on Longay; not seen elsewhere although search was made for it after its detection on the smaller island.

R. rosaria H. Loew.—Abundant on all the islands.

R. rosariella K.—Rare on *Salix repens* just south of Oskaig saltmarsh, Raasay.

R. salicis Schr.—Widely distributed on every island, but not really plentiful; always on *Salix aurita*.

Perrisia angelicae Rübs.—Swollen, closed flowers of *Angelica sylvestris*; common enough along sheltered stream sides on Raasay and Rona.

P. engstfeldi Rübs.—On *Spiraea*, and not rare.

P. harrisoni Bagn.—A few on Longay on Meadow Sweet growing in the shelter of a sallow thicket.

P. filicina K.—Not very common, on every island; galls found on bracken fronds.

P. praticola K.—On *Lychnis Flos-cuculi* flowers near the School House, Dry Harbour, Rona; quite rare and not found elsewhere.

P. lathyri K.—

P. lathyricola R.—Both of these are common, and general, on *Lathyrus pratensis*.

P. loticola R.—On *Lotus* on Raasay and Scalpay.

P. miki K.—Very uncommon on knapweed heads; only noted near Inverarish, Raasay.

P. plicatrix H. Loew.—Everywhere plentiful on various *Rubus* species, galling the leaves.

P. pratensis K.—Rare on meadow vetch, Raasay.

P. pustulans Rübs.—The commonest of the gall gnats attacking *Spiraea Ulmaria*; occurs on all the islands.

P. rosarum Hardy.—Common on many species of rose on every island visited.

P. rostrupiana K.—Rare on Scalpay; foodplant Meadow Sweet.

P. ulmariae Brem.—Abundant everywhere on *Spiraea*.

P. urticae Perris.—Common, but necessarily limited in its distribution to nettles near houses; Raasay, Rona, Scalpay.

P. veronicae Vall.—Only on *Veronicae Chamaedrys*, but on every island except Longay.

Group CECIDOMYARIÆ.

Dishormomyia cornifex K.—Rare near Balachuirn, Raasay on a species of *Carex*.

Syndiplosis petioli K.—Abundant on the petioles of *Populus tremula* on the cliffs above the most westerly of the two lochs on Rona, rare in northern Raasay, and certainly absent from the aspens examined on Scalpay, Longay, and near Suisnish, Raasay.

Contarinia barbichei K.—Common and well scattered on the various islands; foodplant *Lotus corniculatus*.

C. betulicola K.—A bud gall on birch; not really common on Raasay and Scalpay.

C. betulina K.—Forms a leaf pustule on birch; noted wherever that tree grows on the islands.

Stictodiplosis jacobaeae H. Loew.—Attacks flower heads of ragwort; common enough on all the islands, especially along the coasts.

S. scrophulariae K.—Abundant on *Scrophularia nodosa* flowers in Raasay House Woods.

Harmandia tremulae Winn.—Spherical gall on aspen leaves, Rona only.

Mycodiplosis sp.—Reddish larvae, probably referable to several distinct Cecidomyid species, were observed on rusts on *Salix repens* (Rona), on *Taraxacum* (Rona), on *Carduus heterophyllus* (Raasay), on *C. arvensis* (Raasay), on *Euphrasia* (Raasay) etc.

Massalongia rubra K.—Forming a dark purple gall on the midribs of *Betula* leaves; detected on every island.

THE HYMENOPTERA OF THE ISLE OF RAASAY AND OF THE ADJACENT ISLANDS OF SCALPAY, SOUTH RONA, FLADDAY, AND LONGAY.

By J. W. Heslop Harrison, D.Sc., F.R.S.

Most of the Hymenoptera recorded in this list were captured when the Armstrong College Biological Expedition visited the islands in 1935 and 1936, although a few were taken by Dr. G. Heslop Harrison in April, May, and June of the latter year. Owing to the demands of the expedition as a whole, the work on the present group was not so intense as in others. Moreover, in many of the families we encountered not only a dearth of species, but, in addition, a paucity of individuals. Thus the lists in the group are not very long; still, to balance that, in many ways they make up in interest.

APIDAE.

Halictus rubicundus Christ.—Not very plentiful, but taken on ragwort near Inverarish, Oskaig, and Holoman Island.

H. morio Fab.—Only a few odd examples on flowers of *Compositae* and *Rubus* at Oskaig, Point of Eyre, and Brochel, Raasay.

H. leucopus Kirby.—Not uncommon on the coast from Fearns to Suisnish, Raasay.

Andrena analis Panz.—On the pathside near Clachan, Raasay.

A. denticulata Kirby.—Sparingly on the edges of the moorland paths between Inverarish and Brochel, Raasay.

A. rosae Panz.—Not uncommon in the southern portion of Raasay.

A. coitana Kirby.—Not at all uncommon on Raasay and Scalpay.

A. fucata Sm.—In June on the path to Fearns, Raasay.

Psithyrus campestris Panz.—Four females from S. Rona with seven males and females from Raasay. These all seem to be referable to Richards' variety *swynnertoni,* characterised by its superabundance of yellow hairs, recently described from Cara Island.

P. bohemicus Seidl.—Not uncommon and well distributed on Rona and Raasay.

P. sylvestris Lap.—Much scarcer on the same two islands.

Bombus smithianus White.—This usually rare and interesting bee appears to be far from scarce, and is widespread on Raasay, Rona, Scalpay, and Longay, occurring from sea level, as at Eyre Lighthouse, to an altitude of 1000 feet on Dun Caan, Raasay and of 800 feet on Bein Loch a Mhuilinn, Scalpay. It has generally been assumed that its range does not overlap that of its allies *B. muscorum* and *B. agrorum*; to this I can only reply that on the heathery shingle at Eyre I have netted *B. smithianus, B. agrorum, B. muscorum* and *B. soroensis* from the same plant of *Scabiosa Succisa.* Similarly the three allied species fly together throughout the tableland of Longay, and near the upper lochs on Scalpay.

B. agrorum L. race *septentrionalis* Vogt.—Abundant on every island, including Fladday.

B. muscorum L. race *pallidus* Evans.—Also on every island, and found at a height of 1200 feet on Dun Caan, Raasay.

B. lucorum L.—Generally distributed and plentiful.

B. hortorum L.—This species cannot be considered other than local, although it occurs on Fladday. It is, however, abundant enough at *Fuchsia* flowers wherever that plant grows on Raasay.

B. jonellus Sm.—In a form demanding no comment, on every island visited except Fladday.

B. soroensis Fab.—Sparingly on Raasay and Scalpay.

B. lapidarius L.—Really rare, as might have been anticipated from its eastern distribution on the Scottish mainland; two males at N. Fearns, Raasay.

B. ruderarius Mull.—Sparingly on Raasay only, at S. Fearns, Eyre Lighthouse, and near the Pier; always on the coast and at flowers of the Devilsbit Scabious.

FORMICIDAE.

Formica fusca Lat.—Common enough on Rona, Raasay, and Scalpay.

Lasius flavus De G.—Not scarce on Raasay.

Leptothorax acervorum Fab.—Not rare, Rona and Raasay.

Myrmica scabrinodes Nyl.—Common everywhere, and a nuisance on Raasay in 1936.

M. ruginodes Nyl.—Also plentiful on all the islands.

VESPIDAE.

Vespa vulgaris L.—Common in the Inverarish area on Raasay.

V. rufa L.—Equally abundant and in the same area; odd females on Dun Caan at 1450 feet.

V. austriaca Panz.—This wasp, parasitic on the closely allied *V. rufa*, was only found on Dun Caan; queens were shaken from moss in August 1936.

V. norvegica Fab.—Common on Raasay in the various wooded areas.

V. sylvestris Scop.—Taken at figwort flowers in Raasay House Woods.

Odynerus pictus Curt.—Not uncommon at one point near N. Fearns, Raasay.

O. parietinus L.—Sparingly but generally scattered in Raasay.

O. trimarginatus Zett.—Not rare, Fearns, Eyre, Raasay, and N. Scalpay.

FOSSORES.

Crabro dimidiatus Fab.—Common enough along the Arish, Raasay.

Pompilus plumbeus Fab.—Once on the sandy shingle near the Point of Eyre, Raasay.

CHRYSIDAE.

Chrysis ignita L.—Near Fearns, Raasay; common enough.

ICHNEUMONIDAE.

Goniocryptus titillator L.—Raasay.

Rhyssa persuasoria L.—Common in the pine wood just beneath the upper road, Raasay.

Acrotomus sexcinctus Gr.—Raasay.

Glypta elongatus Hn.—Raasay.

CYNIPIDAE.

Rhodites rosae L.—Common upon roses of the *Sherardi* group, like *R. glabrata* and *R. pseudomollis*; curiously enough, only observed on Rona.

R. eglanteriae Htg.—Sparingly on roses of the *Rosa glauca* and *R. Sherardi* groups in S. Raasay and W. Scalpay.

R. rosarum Gir.—Rare on *Rosa glauca* forms on Scalpay.

Xestophanes brevitarsis Thoms.—On *Potentilla* in Central Raasay; not uncommon.

Isocolus jaceae Först.—Thinly scattered on Raasay on *Centaurea nigra*.

*Andricus numismalis** Oliv.—Rather rare on oaks not far from the Manse, Raasay; also in the wood along the Arish Burn.

A. lenticularis Oliv.—Very common on oaks wherever they occur in the islands.

Dryophanta longiventris Htg.—Quite a large number examined in 1934; none seen in 1935 and 1936. Raasay House Woods.

Biorrhiza pallida Rose.—Very rare, Raasay.

Trigonaspis renum Gir.—Rare along the Arish.

Andricus ostreus Gir.—Quite abundant in the woods on the right bank of the Arish Burn.

A. fecundator Htg.—Far from plentiful in the same woods.

A. curvator Htg.—Old galls, Raasay House Woods.

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*In dealing with the Cynipidæ displaying "Alternation of Generations," the name given to the gall actually found is supplied.

TENTHREDINIDAE.

Pontania pedunculi Htg.—Abundant on *Salix aurita* throughout Rona, Raasay, Scalpay, and Longay; I have seen single bushes supporting thousands of galls.

P. viminalis L.—Not common on *Salix repens* growing along the west coast of Raasay.

P. proxima Lep.—Raasay and Scalpay, often on *Salix cinerea* and also on *S. aurita*.

SIRICIDAE.

Sirex gigas L.—In excessive abundance; hundreds were seen flying at once in the pine wood just below the upper road. The ichneumon, *Rhyssa persuasoria*, accompanied them.

THE PSYLLIDAE OR JUMPING PLANT-LICE OF RAASAY AND OF THE ADJACENT ISLANDS OF RONA, FLADDAY, SCALPAY, LONGAY, AND SKYE.

By George Heslop Harrison B.Sc., Ph.D.

The 32 species constituting the present list are the result of intensive work during the past four years. Six visits have been made to the islands, two during the spring and early summer, and the remainder in July and August. I feel, therefore, that, in the case of the island of Raasay to which most attention has been given, there must be little further to add.

Since the earlier Rona list (Scottish Naturalist, May-June, 1935) was published as a result of the visit which I made to that island in 1933, many obvious gaps have been filled in 1934 and 1936. Amongst the species added *Livia juncorum*, which I then said was of most likely occurrence, has been found at several stations both on Rona and Raasay.

The record of *Calophya rhois* for Scalpay is unique; the species, genus and subfamily (Pauropsyllinae) are new to the British lists. Like its host plant, however, it is obviously introduced.

Family *PSYLLIDAE*.
Subfamily LIVIINAE.

Livia juncorum Latr.—In the South Rona list, published in 1935, the remark was made that it seemed strange that this species had not been detected. However, in 1936, adults were swept from a damp meadow at Fearns, Raasay, and my father, Prof. J. W. Heslop Harrison, discovered galls on *Juncus* spp. behind the Schoolhouse on Rona. Subsequently larvae, galls, and adults were found quite commonly at many points, both on Rona and Raasay.

Subfamily APHALARINAE.

Aphalara calthæ Linn.—First noted for Rona in 1933, when it was observed on a large *Polygonum* growing near a ruined croft not far from Dry Harbour; likewise of rare occurrence in Raasay House Woods, Raasay.

A. exilis Web. and Mohr.—After a series of unsuccessful searches for this species it was discovered in spring this year when numerous adults, eggs, and larvae were collected from *Rumex acetosella* behind the church on Raasay. Amongst the hibernated adults, one remarkable immaculate-winged form was taken; this I name var. *immaculata.*

A. nebulosa Zett.—Although the Rose Bay Willow Herb (*Epilobium angustifolium*), the food plant of the species, occurs sparingly on Raasay, the insect has not been captured on that island. This year however, an examination of the plant on the cliffs along the Allt Liath, Scalpay, revealed the characteristic leaf folds induced by this insect. No adults were found.

A. picta Zett.—First detected near Big Harbour, South Rona, on *Senecio aquaticus.* Since then it has been found both on this plant, as well as on *Crepis paludosa* and *Hypochoeris radicata,* at Balachuirn, on *S. aquaticus,* Brochel, and *H. radicata* at Fearns, Raasay. In addition adults were swept from mixed herbage, in which these plants were represented, on Scalpay and Fladday.

Aphalaroida ericae Curt.—Common on *Calluna* and *Erica* on the moorlands of Raasay, Rona, Scalpay, Fladday, Longay, and Skye.

Subfamily PAUROPSYLLINAE.

Calophya rhois Löw.—Four females of this species were collected from *Rhus cotinus,* growing in Scalpay House garden, Scalpay. Although new to the British lists, and representing a new subfamily, it has undoubtedly been introduced with its host plant.

Subfamily PSYLLINAE.

Psylla alni Linn.—Very common on alder on all the islands, but also feeding on birch at South Fearns, Raasay.

P. försteri Flor.—Also very abundant on alder; on all the islands.

P. hippophaes Först.—On *Hippophae rhamnoides* growing near Portree, Skye; most probably introduced.

P. buxi Linn.—Galls and adults from box growing in the garden of the Manse, Raasay, in the garden of Scalpay House, Scalpay, and near Portree, Skye.

P. bagnalli Harr.—Obtained sparingly by sweeping in damp pastures, where it lives on *Juncus* spp. and beaten from Coniferae in late summer and spring; widely distributed on Rona, Raasay, Fladday, and Scalpay.

P. nigrita Zett.—Common on Coniferae near Big Harbour, Rona, but also abundant on *Salix cinerea, S. aurita,* and *S. Caprea* on all the islands.

P. dudai Sulc.—Very plentiful everywhere in summer on various species of *Salix,* and during the spring and autumn on Coniferae and low herbage.

P. brunneipennis Edw.—This species is one of the most abundant of the sallow-feeding species found in the Hebrides. It occurs on every island visited. It exhibits a wide spread of variation in respect to colour, and individuals have been collected ranging from a dirty green or orange to red and black, with numerous white markings.

P. abdominalis M.-D.—Not common, but on various *Salices* on Raasay, Rona, Fladday, Skye, and Longay; not discovered on Scalpay.

P. ambigua Först.—This species occurs with the preceding in early summer on *Salices* and similarly becomes less abundant towards the end of summer; on all the islands.

P. melanoneura Först.—Although its host plant, *Crataegus oxyacantha,* is rather local, this insect swarms wherever the latter occurs; Raasay, Rona, and Skye.

P. pyricola Först.—A few from pear and apple in Scalpay House garden, Scalpay.

P. cratægi Schr.—Not abundant on *Cratægus oxyacantha*, North Fearns, Raasay.

P. peregrina Först.—Very plentiful wherever hawthorn grows on Raasay, Rona, and Skye.

P. sorbi Linn.—Very widely distributed on the islands on mountain ash, often ascending to high altitudes in the upper courses of the streams.

P. mali Schdbg.—On cultivated apple in Raasay House gardens, Scalpay House garden, and near Portree, Skye.

P. ulmi Först.—The two females which I refer to this species were captured from sycamore growing in Raasay House grounds, Raasay.

P. hartigii Flor.—On all the islands and attached to birch. Several forms approaching Edwards *P. venata** were encountered.

P. subferruginea Edw.—Sparingly on birch on Raasay at Balachuirn, and in a gorge behind the Schoolhouse, Rona.

Psyllopsis fraxini Linn.—In great numbers on *Fraxinus excelsior* at Brochel and Inverarish, Raasay; also taken on Skye near Portree.

Ps. fraxinicola Först.—Although not always so abundant as *Ps. fraxini*, this species is as a general rule much more widely distributed in the islands. It was found on all the islands of the present group except Fladday and Longay.

Subfamily TRIOZINAE.

Trioza urticae Linn.—In countless swarms, wherever nettles grow, on the islands.

T. albiventris Först.—A single dead specimen was taken from a spider's web, Inverarish, Raasay.

T. remota Först.—Producing their characteristic 'pit galls' on the leaves, the larvae of this species were

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*I believe that *Psylla venata* Edw. is merely a form of *P. hartigii* Flor., and that the same remark is applicable to *P. bœrneri* H. Haupt.

quite numerous on oak trees in Big Harbour Copse, Rona, very abundant on the same host on Raasay, near Inverarish, and also plentiful on Skye near Portree; not detected on Scalpay, although repeated searches were made.

T. salicivora Reut.—This species occurs near Inverarish, Raasay, where adults were beaten from Coniferae in spring, and, later in June, eggs and young larvae observed on *Salix cinerea* and *S. aurita*. The eggs are very similar to those of *T. albiventris*, and the larvae produce 'pit-galls' on sallow leaves strongly resembling those of *T. remota* on oak.

THE HEMIPTERA—HETEROPTERA OF RAASAY AND OF THE ADJACENT ISLANDS OF SOUTH RONA AND SCALPAY.

By J. W. Heslop Harrison D.Sc., F.R.S.

In 1934 and 1935, owing to the demands made on our time by the work planned in connection with the Flora, and with certain selected insect groups, comparatively little attention was devoted to Hemiptera-Heteroptera. However, as we had early recognised that the Boreal element in the coleopterous fauna, as represented by *Dytiscus lapponicus,* occurred at very low elevations in Raasay, our researches in connection with the aquatic coleoptera were of quite an intensive nature. Naturally, the use of the water net involved the capture of numbers of Corixidae and Notonectidae so that our knowledge of these families may be regarded as reasonably complete. In 1936, on the other hand, every possible method was exploited in investigating the present group, and with a considerable measure of success.

In spite of that, the list cannot be regarded as either satisfactory or final. Too many species are recorded from Scalpay and not from Raasay. Attaching due weight to the much more favourable conditions on Raasay, this points to a falling off in our energies when Raasay was being worked or to some peculiar factor, or factors, governing the occurrence of certain species in Scalpay. In either case further work is indicated.

PENTATOMIDAE.

Palomena prasina L.—Larvae and adults on alder along the Arish, Raasay; apparently new to Scotland.

Pentatoma rufipes L.—Quite rare, but found in all the birch woods on Raasay.

Elasmostethus interstinctus L.—Larvae on birch in August, but adults in April; Inverarish, Raasay only.

Elasmucha grisea L.—Hibernated examples along the Arish, much rarer than the preceding species.

LYGAEIDAE.

Nysius thymi Wolff.—Amongst low herbage on Rona and in the extreme south of Raasay.

Stygnocoris rusticus Fall.—Sparingly amongst thyme, heather, and birdsfoot trefoil on Scalpay and Raasay.

S. pedestris Fall.—On Raasay and Scalpay with the last species.

S. fuligineus Geoff.—Not common on the coasts of Raasay and Scalpay.

Trapezonotus arenarius L.—Scattered in Southern Raasay.

Drymus silvaticus Fab.—Quite scarce in the Raasay woods.

Gastrodes ferrugineus L.—Beaten from Coniferae in some numbers; in the Raasay House Woods.

TINGITIDAE.

Acalypta parvula Fall.—Shaken from moss growing on the rocks above Loch an Leoid, Scalpay, and in similar stations in the Loch Storab area on Raasay; larvae present in April, adults in August.

A. brunnea Germ.—Also from moss, but in the woods near the church, Raasay; larvae in April.

A. nigrina Fall.—Taken from moss and the debris of *Empetrum nigrum* on the upper slopes of Dun Caan, Raasay.

NABIDAE.

Dolichonabis limbatus Dahlb.—Common everywhere on moorlands, shingly ground, etc; Rona, Raasay and Scalpay.

Reduviolus flavomarginatus Schltz.—Also well distributed on the moors of the various islands.

ANTHOCORIDAE.

Temnostethus pusillus H.-S.—Common enough everywhere on various shrubs; seemingly preferring *Salix aurita.*

Anthocoris nemorum L.—Very plentiful everywhere and noted on Longay.

A. nemoralis Fab.—Larvae and adults on various shrubs, chiefly birch, alder, and sallow, in the North of Scalpay; not seen on Raasay.

A. confusus Reut.—Rather rare on various trees in Raasay House Woods.

A. pilosus Jak.—This species is new to the British lists and was taken by Dr. George Heslop Harrison by beating various trees in the woods on the south side of Scalpay; fuller details are reserved for further communications.

CAPSIDAE.

Miris ferrugatus Fall.—Quite common on Raasay; taken by indiscriminate sweeping and beating, from *Angelica* and valerian flowers, etc.

Stenodema holsatum F.—Taken commonly by sweeping; Raasay and Scalpay.

S. laevigatum L.—With the last named insect.

Phytocoris longipennis Flor.—Beaten freely from alder and birch on Raasay and Scalpay, much rarer on Rona.

Adelphocoris lineolatus Gze.—Swept on the shingly heath in the vicinity of the Point of Eyre Lighthouse, Raasay.

Calocoris norvegicus Gmel.—Everywhere abundant on all kinds of low plants.

C. roseomaculatus De G.—Not very common; fairly widespread on banksides in Southern Raasay and Scalpay.

C. sexguttatus Fab.—Distinctly rare in the Brochel area, Raasay.

C. ochromelas Gmel.—In the Raasay House Woods, and on wych elm on the right bank of the Arish.

Lygus pratensis L.—Abounds everywhere in grassy places, Raasay, Rona, and Scalpay.

L. rubricatus Fall.—Beaten from various Coniferae on Raasay and Scalpay.

L. contaminatus Fall.—Beaten from alder and birch on Scalpay, along the Allt Camas na Geadaig.

L. pabulinus L.—Rare in the marsh at Fearns, S.E. Raasay.

L. viridis Fall.—Again, curiously enough, only found on Scalpay; in the southern mixed woods.

Plesiocoris rugicollis Fall.—On *Salix aurita* throughout Scalpay, yet apparently escaping detection on Raasay.

Bothynotus pilosus Boh.—From spruce, larch, mountain ash, etc., and quite well distributed on Raasay.

Monalocoris filicis L.—Extremely rare and beaten from ferns near Oskaig, Raasay; a diligent search was made for this species, although fruitlessly, in many suitable places on all the islands.

Psallus ambiguus Fall.—Not at all uncommon on alder, Raasay and Scalpay; rare on Rona.

P. betuleti Fall.—Rare in the birch woods at Screapadal, Raasay.

P. variabilis Fall.—Abundant in most places.

P. lepidus Fieb.—From mixed woods in southern Scalpay only.

P. falleni Reut.—On birch along the Allt Liath and elsewhere, Scalpay.

P. varians H.-S.—On very many trees on Scalpay, but, like several of its allies, not observed on Raasay.

P. roseus Fab.—Common on *Salices* on all the islands, including Longay.

P. salicellus Mey.—This species, apparently not hitherto reported from Scotland, was captured in some numbers in the woods along the Arish Burn, and generally from *Salix aurita*.

Dicyphus pallidicornis Fieb.—Beaten sparingly from foxgloves at widely separated stations on Raasay, Rona, and Scalpay.

Blepharidopterus angulatus Fall.—From birch, etc., on all the islands.

Mecomma ambulans Fall.—Found in various marshy places around the south east, and south coasts of Raasay, and in the south of Scalpay.

Orthotylus nassatus Fab. On various trees and shrubs in the southern parts of Scalpay.

Plagiognathus chrysanthemi Wolff.—In marshy places at Fearns, Oskaig, Raasay, and in the big marsh near the cultivated land, S. Scalpay.

P. arbustorum Fab.—Not uncommon, with its ally, in southern Scalpay, but not collected on Raasay.

GERRIDAE.

Gerris costae H.-S.—On hill burns, especially in the upper parts of their course, as on the Arish Burn, Storab's Burn, etc., Raasay, and on the Allt Liath, Scalpay.

G. lacustris L.—Common in many places on Raasay, and even on sea water in the pools of Oskaig salt marsh.

G. thoracicus Schum.—Not at all common and excessively local, Loch Eadar da Bhaile, Raasay and on a small loch near Loch a Mhuilinn, Scalpay.

G. odontogaster Zett.—Scarce on Scalpay and Rona.

VELIIDAE.

Velia currens Fab.—Abundant in all suitable places on all the islands, including the mountain torrents.

ACANTHIIDAE.

Salda littoralis L.—In the salt marsh at Dry Harbour, Rona.

S. morio Zett.—Abundant along the shores of Loch na Mna and Loch na Meilich, Raasay.

Acanthia scotiça Curt.—Quite rare, high up the Arish.

A. saltatoria L.—Far from common, Loch Eadar da Bhaile, Raasay.

NOTONECTIDAE.

Notonecta glauca L.—Not at all common in pools on Raasay, but quite abundant in all the Rona lochs.

N. obliqua Gall.—Although a careful watch was kept for this species and all suitable lochs examined, it was only captured in a deep peaty lochan in the centre of Scalpay and in Loch Braig, Rona. It has been captured by Dr. G. Heslop Harrison on Coll.

CORIXIDAE.

Corixa geoffroyi Leach.—Common on Raasay and Rona, but not seen on Scalpay.

Arctocorisa scotti D. & S.—Very abundant in all suitable lochs on Raasay, Rona and Scalpay.

A. castanea Thoms.—This species, recently recognised as British, is far from uncommon on Raasay and Rona.

A. fossarum Leach.—Local on Raasay.

A. fabricii Fieb.—Found in the more low-lying lochs of Raasay in the west-central area.

A. striata L.—Quite common, from the lowest pools to Loch na Mna, also on Rona; generally where streams leave the various lochs.

A. distincta Fieb.—In the small pool in the angle between Loch a Mhuilinn and Loch an Leoid on Scalpay, but there plentiful; not seen elsewhere.

A. sahlbergi Fieb.—Common enough on all the islands.

A. limitata Fieb.—In Loch na Meilich, just under Dun Caan, not common.

A. venusta D. & S.—On Rona in the stream draining Loch Braig and there common, much scarcer in the stream which leaves Loch Eadar da Bhaile, Raasay, and on Scalpay.

Callicorixa praeusta Fieb.—This occurred sparingly in smaller peaty pools on Raasay and Scalpay; absent from the larger lochs.

C. wollastoni D. & S.—Not common in the same areas as its ally.

Cymatia bonsdorffi C. Sahb.—In the lochans just under Sithean Glac an Ime, Scalpay; not common.

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STUDIES OF THE TONE-QUALITY OF ORGAN PIPES.

1. THE INFLUENCE OF WIND PRESSURE ON THE QUALITY OF FLUE PIPES. BY M. MOKHTAR, M.SC.[1]

THIS investigation was undertaken to show how the tone of a flue pipe changes with the blowing pressure, and to illustrate the theory of the tone production in such pipes.

Apparatus.

An open organ pipe, having a natural frequency of 288, is blown under constant pressure from a reservoir fed by weighted bellows. Sound waves produced in air in the vicinity are picked up by a microphone, amplified and then applied to one pair of deflecting plates of a cathode ray oscillograph. The wave form is recorded by photographing the motion of the electron spot on a cinematographic film fitted into a revolving camera, the film travelling in a direction at right angles to that of the electron spot.

Theory.

The origin of the tone production in an organ pipe lies in the edge tone which is produced at the mouth and which is due to the vortices formed as the air leaves the slit and strikes the edge formed by the bevelled upper lip of the mouth.[2] As the wind pressure (P) increases, the efflux velocity (V) increases according to the relation $P=\frac{1}{2}\rho V^2$ where ρ is the density of the air, so that $P \propto V^2$.

The edge tone, if uncoupled from the pipe, will rise continually in pitch by the increase of the blowing pressure, so that

---

[1] Lecturer in Physics, University of Cairo; visited Armstrong College in the summer of 1936 for the purpose of doing research in acoustics, under a grant from his University.

[2] Cf. Richardson, *Sound*, 2nd ed. (1935), pp. 175-8.

$$\frac{Vj}{nf} = \text{constant.} \quad (j = 1, 2, 3 \ \ldots$$

where f is the height of the mouth (distance from slit to edge), and n is the frequency of the tone produced. The relation between n and V or n and $\sqrt{P}$ is represented graphically by the dotted line AB (fig. 1).

At low pressure, however, the pitch of the edge tone is liable to jump to the octave due to the formation of additional eddies between slit and edge, and run as indicated by the dotted line XY (fig. 1).

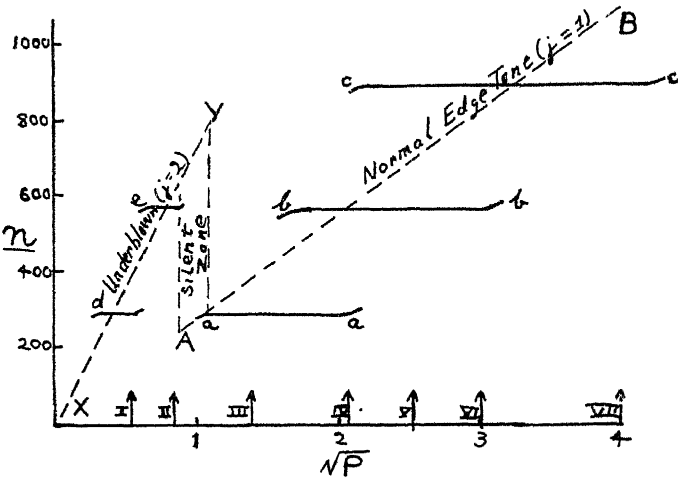

FIG. 1.

When the edge tone is coupled to a column of air as it is in the case of these organ pipes, the actual tones produced are limited to the natural frequencies of the air column. A certain amount of accommodation takes place between pipe and edge tone, but whereas the edge tone may be considerably pulled out of its natural period of vibration in order to secure equality of period, that of the column of air is variable to a very small extent as shown by the small kinks at the ends of the full lines aa, bb, etc. (fig. 1).

To exemplify the property of coupling, we may suppose the blowing pressure to be continually increased beyond the normal. As V is increased, the natural frequency of the edge tone rises beyond the fundamental of the pipe, but the latter being the stronger partner in the couple, succeeds in forcing its own period upon the edge tone, until the natural frequency of the edge tone if isolated would be nearer to the first overtone of the pipe than the fundamental. Up to this moment, the frequency of the coupled system has remained in the neighbourhood of the fundamental of the pipe, but now a jump occurs to the overtone, both the edge tone and the pipe tone rapidly picking up the new frequency which they retain with slight alteration until a jump to the next overtone takes place.

Actually, the behaviour is more complex in that the overtones usually appear before the fundamental has ceased, producing a complex note. The procedure is shown by the thick lines aa, bb, cc (fig. 1), representing the fundamental and its first and second overtones overlapping for values of pressure lying between 2 and 4 cms. of water. Oscillogram III (fig. 2) shows the presence of these two overtones in the note produced at a pressure of 2 cms. of water. At a pressure slightly above 4 cms. of water, the fundamental disappears and the octave becomes more distinct but still overlain to a certain extent by the higher overtones. This is verified by the oscillogram IV taken for a pressure of 4·16 cms. of water. At higher pressures the oscillograms V, VI, VII are taken for 6·37, 9, 16 cms. of water respectively. The corresponding positions of these oscillograms are shown on the pressure axis of fig. 1.

The converse phenomenon of the under-blown pipe represents several items of interest. Suppose V to be continually decreased below the normal. Very soon the edge tone will be so far below the pipe tone that the latter ceases to sound. But now the two systems being still coupled, the pipe is still endeavouring to impose one or other of its tones upon the vortex production at the mouth, and in an endeavour to conform, the edge tone reduces its pseudo "wavelength" to $\frac{1}{2}$f or $\frac{1}{3}$f and the same note is again but feebly elicited. Thus if the fundamental is normally produced at V_1 so that V_1/n_1f_1=constant, it may also be produced under conditions given by $\frac{\frac{1}{2}V_1}{n_1\frac{1}{2}f}$=constant, or the octave (in the case of an open pipe) given by $\frac{\frac{1}{2}V_1}{2n_1\frac{1}{4}f}$ =constant.

Oscillogram I shows the underblown fundamental, elicited at a pressure of ·26 cm. of water. At a pressure of ·65 cm., the underblown fundamental disappears, and the sound consists mainly of the underblown octave as shown by oscillogram II. Thereafter follows a "zone of silence" (indicated on fig. 1) before the fundamental is reproduced at normal pressure as in oscillogram III. This silent zone is due to the great extent of mistuning between the pipe and edge tone at these pressures as well as to the instability of the latter, which causes the pipe to cease to speak.

With a stopped pipe, similar results were obtained, except that the first overtone is the twelfth of the fundamental. Oscillograms VIII, IX and X for pressures of 1·46, 6·0 and 16 cm. respectively indicate three stages in the production of overtones of a stopped pipe for which the fundamental (shown on VIII) had a frequency of 230 vibrations per second.

ACKNOWLEDGEMENTS

I wish to offer my thanks to Dr. E. G. Richardson, under whose direction this work was carried out, for his help and advice, and also to Prof. W. E. Curtis and the authorities of Armstrong College for placing the resources of the laboratories at my disposal.

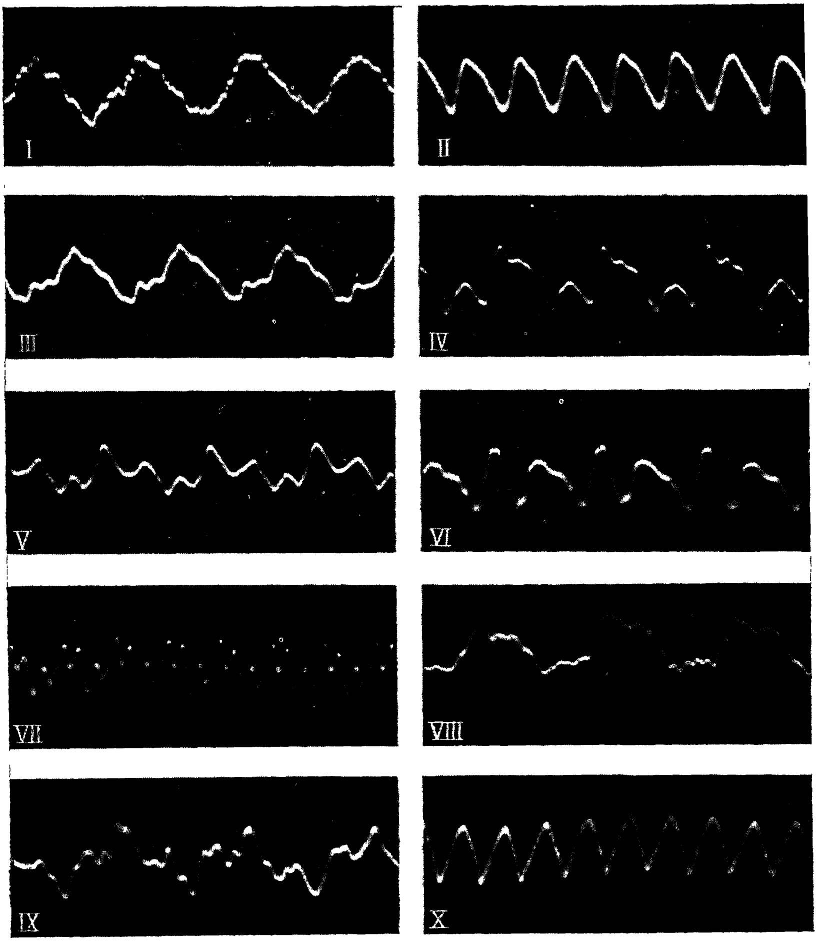

FIG. 2.

INTO IRON PYRITES.

By J. A. Smythe.

The objects described below were found some little time ago during building operations behind the Handyside Arcade, Percy Street, Newcastle, and sent as curiosities to Mr. Russell Goddard of the Hancock Museum. From their appearance and great depth of occurrence (14 to 16 feet) they were thought, by the workmen who unearthed them, to be fossil remains.

The find consists of three objects: (1) an iron bolt 13·75 cm. long and 2·6 cm. in diameter, which fitted loosely and somewhat eccentrically into (2) an annulus, the internal diameter of which was 3·2 cm. and the external 5 cm. The annulus fitted snugly into (3) a fragment, part of a block, of coarse-grained sandstone. Both annulus and sandstone were fragmentary, the bolt was almost complete. These objects will now be described in the order given.

(1) The bolt is almost circular in section and has three longitudinal rows, three in each, of shallow circular indentations, like punch-marks. One end is fish-tailed, the other apparently fractured and the surface is very deeply corroded, exhibiting narrow longitudinal ridges and grooves having all the appearance of wrought iron which has undergone extensive corrosion. Metallographic examination of the metal shows it to be, indeed, a wrought iron of ordinary quality, the slag-fibres being lengthwise disposed. The S.G. of the metal is 7·67. A whitish incrustation on the surface of the bolt was found to consist of ferrous sulphate. Mr. H. E. L. Martin informs me that this is a typical Rag or Lewis bolt, such as is commonly sunk in a lead- or cement-filled hole in stonework, and used for bolting down bed-plates and the like.

(2) The annulus proved to be of exceptional interest. The inside surface, on scraping, yielded small particles of metallic iron; the outside surface has visible patches of

sulphur; the general appearance of the whole is dark grey, with yellowish speckles of sulphur, and it was found to take an excellent polish, of a bronze-like colour, like iron pyrites. Its S.G. is 3·94. Analysis yielded the following results:

Insol. in HNO_3	0·50	S (total)	50·88
Fe (total)	43·83	S (free)	5·60
Fe (as sulphate)	0·62	S (as monosulphide)	1·14
$Fe_2O_3+Al_2O_3$	63·56	S (as sulphate)	0·31
TiO_2	tr.	H_2O (at 105° C.)	2·32
CaO	tr.	H_2O (in vacuo)	0·90
MgO	nil.		

The material yielded an extract, soluble in water, containing FeO, 0·80; SO_3, 0·77; CaO, tr.

The remainders of iron and sulphur, after allocation of these elements to monosulphide and sulphate of iron and to elemental sulphur, are 41·20 per cent. of iron and 43·83 per cent. of sulphur, and these quantities must be referred to iron disulphide. The iron here is slightly in excess of the pyritic ratio, the figures agreeing with the formula Fe_8S_{15}. This is probably due to the presence of a small amount of metallic iron. Allocation of the water has only been possible by direct comparison of the behaviour of ferrous sulphate, under the same conditions of dehydration as were used in the analysis of the material of the annulus.

The proximate composition of the annulus thus works out to:

FeS_2	85·03	
FeS	3·14	
$FeSO_4,7H_2O$	2·87	
S	5·60	
		96·64
Insol. in HNO_3	0·50	
Al_2O_3	0·90	
TiO_2	tr.	
CaO	tr.	
MgO	nil.	
H_2O	1·76	
		3·16
	Total	99·80

(3) The only point of interest about the sandstone is that it is free from infiltrated iron except at the actual plane of junction with the annulus.

From what has been said already, it appears fairly certain that the iron bolt was originally secured in the stone block by embedding it in cement. If we assume this to have been Portland cement of ordinary composition (CaO, 64; Al_2O_3, 10; SiO_2, 22 per cent.), then it is evident that the cement has been almost completely replaced by the pyritic material and, further, that the deposition of the latter has been restricted to the space originally occupied by the cement. The free space between bolt and annulus should thus represent the amount of iron dissolved from the bolt and deposited in the annulus. Calculations based on the data already given and on the assumption that the bolt contains 97 per cent. of iron show that the bolt has lost 280 grams of metal and that 275 grams have been deposited in the annulus.

The formation of iron pyrites from salts of iron under natural conditions and in laboratory experiments with simple reagents, at ordinary temperature, was studied a century or more ago, G. Bischoff,[1] in particular, establishing the ease of reduction of sulphates of the alkalies and alkali-earths by organic matter, and the conversion of iron salts, in their presence, into iron pyrites. A local example of some interest, in this connexion, was described by the late Dr. D. Woolacott[2] of a modern conglomerate on the coast near St. Mary's Island. This consisted of iron rivets and shore-materials, bound into a solid mass with a ferruginous cement, which contained ferrous sulphide and some perfect cubes of iron pyrites, obviously formed *in situ*. The rivets were greatly corroded, showing the disposition of the slag-fibres, and their surface was almost identical in appearance with that of the bolt under discussion. There was convincing evidence from the nature of the constituents of this conglomerate that its formation had taken place within eighteen years.

There can, therefore, be no reason to think that the reactions which have led to the formation of the pyritic annulus are of anything but comparatively recent origin, though doubtless they took several years for their accomplishment. Of the conditions which have conduced to them, it is not possible to state much with any degree of certitude; no trained observer was at hand, at the time, to collect collateral evidence, and subsequent efforts to get further information on the subject have been fruitless. Any postulated set of conditions must be competent to explain the extensive corrosion of the iron, the removal of the cement in solution, the formation of iron pyrites in accordance with the chemical reactions described above, and the metasomatic replacement of the cement by pyrites.

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[1] *Elements of Chemical and Physical Geology.* Eng. Ed. 1854. Vol. I, p. 164.

[2] *Trans. Nat. Hist. Soc. Newcastle.* 1908. Vol. III. Pt. 2.

The simplest assumption is that sulphuric acid, in presence of an organic reducing agent, was the reagent concerned. The amount of this acid requisite to furnish the sulphur in the annulus (320 grams) is 980 grams, and more would be needed to dissolve the cement. The quantity is thus quite considerable and it would appear that some effluent of chemical origin was concerned in the process.

THE BUILDING OF MOLECULES*

By

R. ROBINSON, M.A., D.SC., LL.D., F.R.S.

The aphorism that " there is nothing new under the sun " applies in science only to the exceptions that prove the rule for nothing is more easy to realise or more difficult to explain than the fact that we live in an age characterised by a rapid and unprecedented expansion of discovery and invention.

Assuming certain induction periods, the steep upward bend in the curve of progress may be attributed to the teaching of philosophers such as Francis Bacon, to the invention of the Printing Press, to the rise of an intelligent Middle Class, to the foundation of learned societies such as our own Royal Society, or to certain other economic, social or intellectual conditions. The truth, however, is probably that all these phenomena are but correlated manifestations of some deeper cause of historical discontinuity, a phrase which I apply in the present connection only, and to the observed change in the rate of development of our knowledge of Nature.

The circumstances have evidently been analogous to those of a supersaturated solution in which crystallisation is induced by the introduction of a tiny crystal of the solute or, more exactly, to those of an auto-catalysed reaction. Such analogies are clearly applicable to the acceleration in the accumulation of knowledge that arises from the interactions and reactions of discovery and invention, of working hypothesis and theoretical system, and of the different branches of science.

Less than a fortnight ago, Professor Svedberg of Upsala assisted in the installation of one of his wonderful ultracentrifuges at Oxford. This instrument, the product of the most refined engineering technique, gives results demanding advanced methods in physics and chemistry for their interpretation, but its outstanding application is as a new tool in biochemical and even in biological researches. Applying a centrifugal force up to 300,000 times gravity obtained by 60,000 R.P.M. to solutions, the effects of diffusion can be counteracted and sedimentation of the heavier molecules occurs in part.

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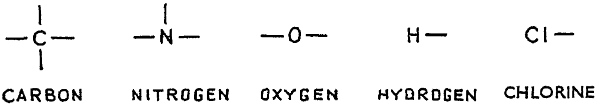
* The Nineteenth Earl Grey Memorial Lecture, delivered at Armstrong College March 10th, 1937.

To give one example, Svedberg has shown by means of the ultra-centrifuge that minute concentrations of thyroxin, the hormone of the thyroid gland, are able to break up the associated protein thyroglobulin into smaller molecules. The action is selective and specific, and although the signficance of the observation has not yet been fully grasped, it has disclosed a state of affairs of great biological interest.

Reflecting on these lines and coming now to the subject of this lecture, it is no longer surprising that the science of structural organic chemistry is of such recent growth. The necessary precedents were the development of atomic and molecular theory. When this foundation was secure, an army of workers, already equipped with adequate general chemical technique, concentrated on the erection of an edifice which must be regarded as one of the towering achievements of mankind. The system of organic chemistry, within its obvious theoretical limits, is one of the most complete and satisfying in the realm of science and it has been constructed during the last ninety or a hundred years.

There is no suggestion that the task has been completed, but a vast territory has been conquered and each gain consolidated. At every point of the boundary further exploration is proceeding and in addition the ground already covered is being more intensively cultivated.

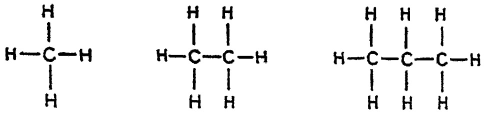
The routine in the study of compounds of carbon includes two types of investigation, namely analytical and synthetical. In both cases the fundamental theory is that a pure substance is a collection of identical molecules in each of which the constituent atoms are arranged in a definite and identical manner. Analysis, not to be confused with the determination of the atomic species in a compound, or with the separation and identification of the components of a mixture, aims at the determination of the structure of the molecules. Naturally we must first know the number of each of the kinds of atoms comprising the molecule, but we may pass over this step because it represents a stage that can always be reached by applying standard methods of elementary analysis and of determination of molecular weight. The classical organic chemist soon found that a very simple theory of the mode of linking of different kinds of atoms provided the key to molecular structure. For many reasons it was thought that a carbon atom could be linked to four atoms, a nitrogen atom to three,* an oxygen atom to two, and a hydrogen atom or a chlorine atom to only one other atom. The symbols used to represent these combining powers or *valencies* were:



As a result of the rapid growth of knowledge of the electrical constitution of matter, we are now in possession of a very satisfying theory of valency. To put it somewhat crudely, the bonds are " made of electrons " or units of negative electricity. But the conception of electrons as corpuscles has given place to that of stationary waves capable of diffraction and localised only as the result of the operation of probability functions. The wave-mechanics of the atom is gradually supplying mathematical justification of the chief tenets of classical valency theory and is naturally taking us very much further in many directions. The simpler mode of expression suffices, however, for most purposes and we will now note some of its consequences.

As I understand that some members of this audience may be " unversed in the art," one or two examples of the application of the hypothesis of valency may be given.

If the valency theory is valid, then every compound of carbon and hydrogen (hydrocarbon) must have a kernel of carbon and be clothed in hydrogen. Thus we arrive at such theoretical possibilities as



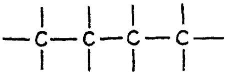
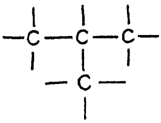
CH_4 C_2H_6 $(CH_3—CH_3)$ C_3H_8 $(CH_3—CH_2—CH_3)$

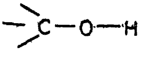
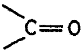
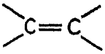
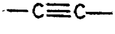
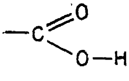
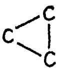
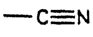
which are the first members of a series $C_nH_{2n}+_2$. Now the experimental fact is that although C_n may be found in combination with less than 2n + 2 atoms of hydrogen, a larger number can never be introduced. Very many substances of the general formula $C_n H_{2n+2}$ are known and their chemical properties justify us in classing them together. The first member of the series is methane, CH_4; a higher member is hentriacontane, $C_{31}H_{64}$, which occurs in many plants.

---

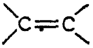
* In certain cases the valencies can be increased and then each extra unit of valency involves the assumption of a positive charge. Thus NH_3 and $NH_4+\}$ Cl. Carbon does not exhibit this type of increased valency.

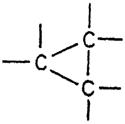
A second deduction from the valency laws that can be tested concerns the possibility of different structures related to one and the same molecular formula. Thus CH_4, C_2H_6, C_3H_8 can only be arranged in one way and only one substance of the formula CH_4, only one of the formula C_2H_6, and only one of the formula C_3H_8, is known. On the other hand, C_4H_{10} can be arranged in two ways and two different substances of the formula C_4H_{10} have been described; this is an example of *isomerism*. With a few exceptions, the full number of isomerides predicted by the valency theory have been isolated and examined in the simpler cases, but the theoretical possibilities in the more complex molecules make this an unmanageable proposition. Thus C_6H_{14} has 6 isomerides and all are known, C_7H_{16} has 9 isomerides of which 7 are certainly known, $C_{13}H_{28}$ has 802 isomerides and only one or two are known. There could be no difficulty in making many new substances of the formula $C_{13}H_{28}$, but it would be sheer waste of time to undertake such labour. As the early work progressed it became recognised that certain groupings of atoms conferred special properties and could thereby be recognised; such characteristic groups are exemplified by the following: —

These expressions also indicate why C_n may combine with less than $2n+2$ hydrogen atoms.

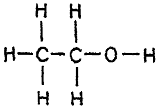




AND $—C\equiv C—$

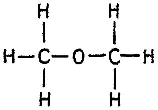
when clothed with hydrogen become C_2H_4, C_3H_6 and C_2H_2 respectively.

In addition to the deductions from the valency theory, the transformations of the simpler carbon compounds were closely studied and their interrelations were of primary importance in the elucidation of structure. Thus ordinary alcohol has the formula C_2H_6O and this might have one of the structures



$CH_3.CH_2.OH$

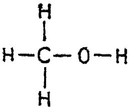
OR



$CH_3.O.CH_3$

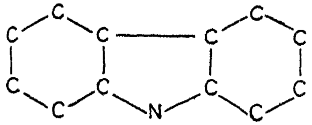
In point of fact, *one* other substance, C_2H_6O, is known; it is a gas at the ordinary temperatures. Now alcohol is readily converted into C_2H_5Cl, C_2H_4O, $C_2H_4O_2$, C_2H_6 and C_2H_4,—i.e. all C_2 compounds. The gaseous C_2H_6O will only give C_2 compounds by replacement of the hydrogen by something else; the theory provides for this behaviour. It is, however, more readily converted into C_1 compounds, namely CH_3Cl, CH_4O, CH_2O, CH_2O_2.

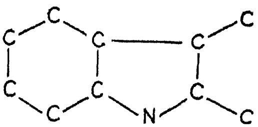
Therefore alcohol probably possesses the first structure. This contains $-\overset{\diagdown}{\underset{\diagup}{C}}-O-H$ and alcohol exhibits the properties which we have learned to associate with this group and which are also characteristic of CH_4O. On the valency theory CH_4O can only be

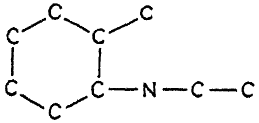


$[CH_3.OH]$

More complex molecules are degraded in as many ways as possible until simpler molecular species of known structure are obtained. The jig-saw puzzle must then be solved; it has often proved very difficult and occasionally has defied sustained attack. As an example of a complicated molecule the architecture of which is still under discussion we may look at the case of strychnine, $C_{21}H_{22}O_2N_2$. The molecular weight is 334 which compares unfavourably with the 17,000,000 of the tobacco-mosaic virus and certain other proteins, but the complexity is of a different type and resides in the fusion of seven rings of atoms. The following fragments of known constitution have been obtained by degradation (skeleton formulæ without hydrogen):

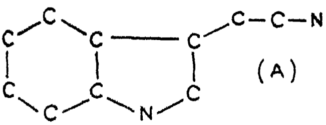






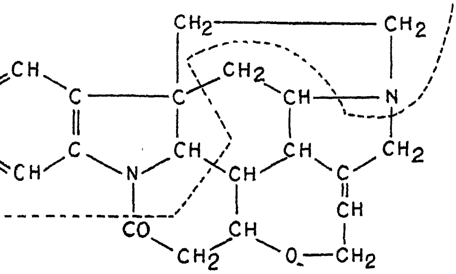
C—C—C

C—C



(A)

Consideration of the course of the degradations and of the whole chemistry of the alkaloid has led me to put forward the annexed structure by means of which every property and reaction can be accommodated. Nevertheless, the solution arrived at may not be unique, because the confirmation of synthesis is lacking.



The dotted line shows how the molecule may be dissected so as to obtain the fragment (A) recently isolated independently by Clemo and by Kotake.

In many cases the constitutional formulæ denoting the mode of linking of the atoms correspond to more than one structure in three dimensions, and it is the province of stereochemistry to establish the space arrangement and even to measure the distances between the atoms. It is hardly germane to my present topic to enter this fascinating field, although it is of the greatest importance. It will suffice to mention that Pasteur laid down for all time the fundamental principles of molecular symmetry and asymmetry. In some of the most elegant experiments ever made he demonstrated that molecules may exist in non-superposable mirror-image forms. He realised that asymmetry cannot be detected by symmetrical means and he showed how to separate the right-hand molecule from the left-hand, the male screw molecules from the female screw molecules by employing various asymmetrical devices. Van't Hoff and Le Bel independently indicated the structural conditions for molecular asymmetry on the hypothesis that the carbon atom joined to four other atoms is tetrahedrally environed. Experiments on the diffraction of X-rays by crystals and of electron beams by molecules in the vapour state have given direct physical confirmation of the validity of models built in accordance with Van't Hoff's theory.

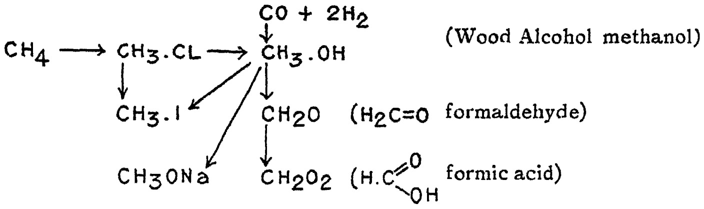
The molecular structure arrived at by analytical methods should be confirmed by synthesis whenever this is feasible, for only then may it be said to be established beyond question. Just as in analysis we noted certain groups that can be diagnosed by means of general reactions, so in synthesis we have gradually learned how to modify existing groupings, to add others in a definite manner and to build up molecular structures in unambiguous fashion. The starting points are almost always substances of known structure, accepted members of the family, whose systematic *bona fides* is such that any chemist who could prove them to be masquerading would at once become world-famous. Few reputations, however, will be acquired in this way.

The earlier work associated with the names of such pioneers as Williamson, Wurtz, Kolbe, Frankland and Kekulé was largely undertaken in connection with the foundation and elaboration of the theoretical system. About the middle of the nineteenth century controversies were rife in regard to the nature of such simple substances as alcohol, C_2H_6O, and acetic acid, $C_2H_4O_2$, and the outcome of these chemical discussions went far to establish the validity of the present accepted system of relative molecular weights. Especially important were Williamson's experiments on the synthesis of ethers because they could not be harmonised with the view held by some chemists that alcohol was $C_4H_{12}O_2$ ($2\ C_2H_6O$).

Berthelot was the first to study organic synthesis systematically. He was able to construct the molecules of the simple carbon compounds such as CH_4, C_2H_4, C_2H_6O, CH_2O_2 etc. from their elements. By way of these and other points of departure the scope of total synthesis was gradually enlarged until to-day it is almost easier to give the categories that remain unsynthesised than to enumerate the types of molecules unambiguously constructed.

A very important starting point, synthesised by Berthelot, is the hydrocarbon benzene, C_6H_6, which was discovered by Faraday in 1825 in a compressed illuminating gas made by the Portable Gas Company of London by thermal decomposition of fish oils. It was encountered as a decomposition product of gum benzoin in 1834 and isolated from coal tar in 1845. This hydrocarbon is the parent of an enormous number of natural products and other carbon compounds of which many are valuable as pigments, dyes, drugs, antiseptics, plastics, explosives, perfumes, etc., etc. Berthelot obtained it by heating acetylene, C_2H_2 ($3\ C_2H_2 \rightarrow C_6H_6$), and Kekulé in 1866 put forward the suggestion that its molecule comprises a symmetrical closed ring of six carbon atoms each bearing a hydrogen atom. This view has been amply confirmed by later synthesis.

The following table shows in schematic form some of the syntheses bearing on the matters already discussed:



(Na = atom of metal sodium)

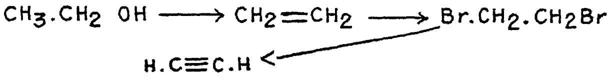
$CH_3I + NaO.CH_3 \longrightarrow NaI + CH_3.O.CH_3$

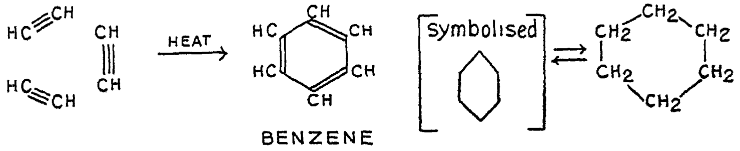
$CH_3.O.CH_3$ is a gas of the formula C_2H_6O

CH_3I Na Na $I.CH_3 \longrightarrow 2NaI + CH_3.CH_3$

Then as above $CH_3.CH_3 \longrightarrow CH_3.CH_2Cl \longrightarrow CH_3CH_2OH$

$CH_3.CH_2.OH$ is Alcohol, C_2H_6O.



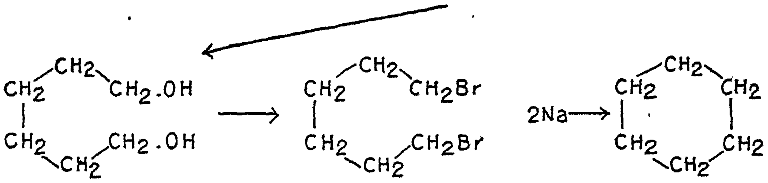


$Br.CH_2.CH_2Br \longrightarrow CN.CH_2.CH_2.CN$

$\longrightarrow HCO_2.CH_2.CH_2.CO_2H \longrightarrow$

$HCO_2.CH_2.CH_2.CO_2.CH_3 \longrightarrow NaCO_2.CH_2.CH_2.CO_2CH_3$

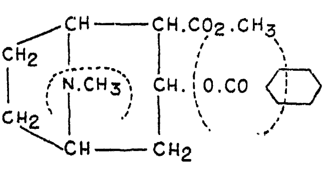
$$\begin{array}{lcl} NaCO_2.CH_2.CH_2.CO_2Me & & CH_2.CH_2.CO_2Me \\ \text{Electrolysis.} & \longrightarrow & | \\ NaCO_2.CH_2.CH_2.CO_2Me & & CH_2.CH_2.CO_2Me \end{array}$$



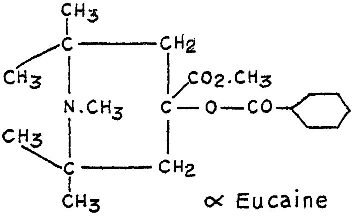
From 1860 onwards the technique of synthesis was continuously improved and the ambition of the organic chemist mounted as his resources were enlarged. The amino-acids—bricks of the enormous protein molecules, glycerol, creatine, uric acid, caffeine, plant alkaloids, natural colouring matters, essential oils, the simple sugars, and many other classes of naturally-occurring substances have been made artificially. In addition a very much larger number of organic molecules not found in Nature have been prepared by methods that establish their molecular structure. Many of these may be utilised in one way or another in the Arts, whilst others fill gaps in the system or were prepared in the course of varied theoretical investigations. Physical chemists find in synthetic organic compounds the most valuable material for the study of the mechanism of chemical change, pharmacologists strive with their aid to establish relations between physiological properties and constitution and indeed there is hardly a branch of science that does not owe a deep debt to the synthetic organic chemist.

We are confident that the future progress of physiology and medicine must be bound up with that of the study of the complex organic compounds which exercise functions of the most vital importance to the organism. Such are, for example, the vitamins, hormones, lipoids, specific proteins and immunity polysaccharides.

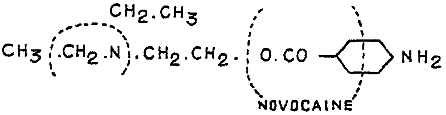
A passing reference with only a few examples is appropriate here to the synthesis of new drugs and to the subject of chemotherapy founded by Paul Ehrlich. The imitation of the main features of the molecule of the natural alkaloid cocaine was at first a close one, and quickly led to a series of local anæsthetics which, however, had the disadvantage of irritating properties. It was then found that the anæsthetic property depended on a small portion of the molecule only, and a much greater field was opened. Several synthetics are now largely employed as local anæsthetics, and the formulæ below show cocaine (which has itself been artificially prepared), α -eucaine which is anæsthetic but irritant and novocaine which is non-irritant, of low toxicity, and a powerful local anæsthetic. The portions of the molecule to be compared in cocaine and novocaine are indicated by the dotted lines.



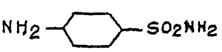
COCAINE



α Eucaine



NOVOCAINE

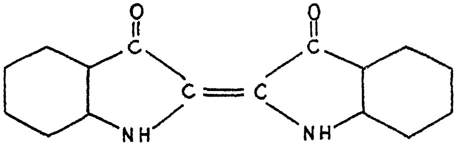


SULPHANILAMIDE

It is well known that synthetic organic substances have been prepared which have a specific therapeutic action in diseases of protozoal origin, for example syphilis, malaria and trypanosomiasis, but until recently no bacterial infection could be controlled in this way. It is therefore a discovery of great importance and promise that a simple benzene derivative, namely sulphanilamide (above) has been found effective against virulent strains of haemolytic streptococci. Most encouraging reports continue to be received from hospitals of its value in cases of puerpural fever and analogous conditions, and a great field of investigation has been opened up. Nothing could be more welcome than the Government Grant of £30,000 per annum, for an initial period of seven years, to found an Institute of Chemotherapy in this country.

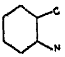
It is obviously impossible to cover the field of organic synthesis and, as I can pick out only a single thread from the skein, the colouring matters seem to afford an appropriate choice. It is indeed an inevitable choice, because the researches of A. von Baeyer (round about 1880) on Indigo Blue were developed with such daring originality and with the aid of so many new methods as to constitute a fresh point of departure in synthetic chemistry and also, as a corollary, in its industrial applications. The novelty of Baeyer's conceptions is well indicated by the ridicule poured on some of them by Kolbe, a respected name in other connections. In this matter Baeyer was in the good company of Van't Hoff and time has brought its revenges. Few boomerangs return with such force and accuracy as those launched by witty but intolerant senior scientists; alas, it is usually only their reputations that suffer.

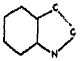
The only aspect of Baeyer's pioneering work that I wish to consider now is the use of synthesis to supplement inconclusive analysis. The degradation data indicated the following molecular structure of indigotin; but did not establish it with certainty in all respects.

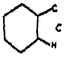
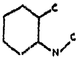
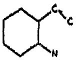


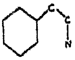
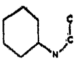
Baeyer applied the jig-saw idea to the problem, but he fitted known fragments together instead of recognising pieces of the broken molecule. Naturally the shape and composition of the pieces gave some indication of the way they might be expected to fit together. The anticipations were tested when necessary by independent analytical and synthetical work on the intermediate stages.

Some of the indigo syntheses are shown in skeleton outline below, and it will be appreciated that each method has a bearing on the question of structure. The stages of the argument are as follows:

(*a*) The structure of simple benzene derivatives containing  had already been elucidated; several of these compounds were useful standards of reference.

(b) The indigo molecule was easily halved forming substances containing  This molecule was synthesised

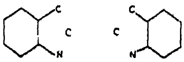
from   

 and  that is to say in all the

possible ways, by introducing the missing bonds. The processes used were of course based on simpler analogies and were calculated to effect the desired changes and no others

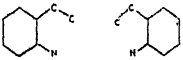
(c) The Indigo Blue syntheses were effected through intermediates, as shown below:—

(1)



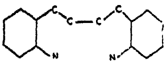
This synthesis from four fragments gives very little new information.

(2)



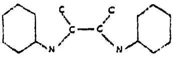
This scheme from two similar halves gives a little more light; the skeleton corresponds to several different syntheses.

(3)



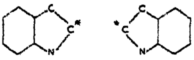
A substance conforming to this skeleton was made by unambiguous methods; its conversion to Indigo Blue shows that the two benzene nuclei are joined by four carbon atoms in line-ahead formation.

(4)



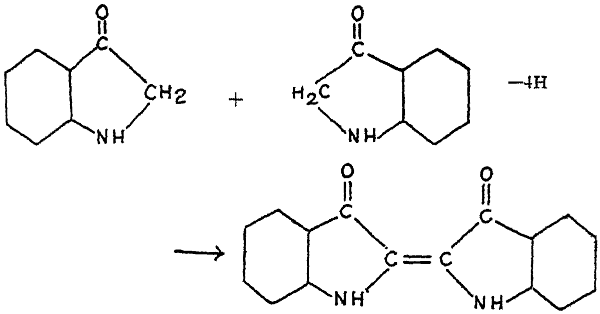
A synthesis on these lines was made subsequent to Baeyer's work; it also employs an intermediate of unambiguous constitution.

(5)



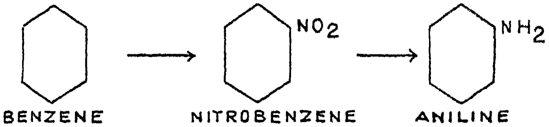
The syntheses here indicated include the earliest known as well as that by which natural Indigo Blue is obtainable from a colourless plant product.

In most examples conforming to this type the union of the asterisked carbon atoms is rendered very probable by the circumstances. For example:

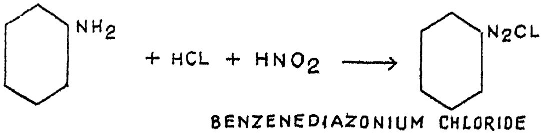


This is the last stage in the manufacturing process now employed and it is one example of many that indicates the position of the oxygen atoms in the molecule.

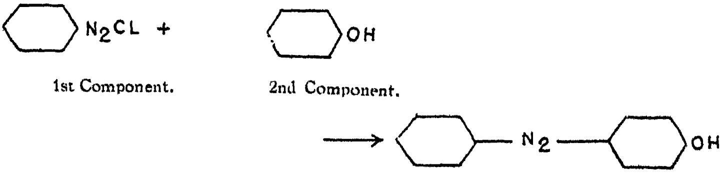
Secondly we may turn our attention to a group of industrial importance. Benzene is treated with nitric acid and the product is heated with iron filings, water and a little acid. In this way the substance known as aniline is manufactured in very large quantities.



In 1858 Griess discovered that when aniline was dissolved in dilute hydrochloric acid and treated with nitrous acid, it yielded a new type of compound, the simplest diazo-salt.

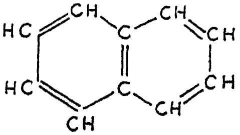


This salt undergoes many useful transformations but the one of greatest industrial importance is its very facile coupling with other benzene derivatives, which have OH or NH_2 groups attached to the nucleus.

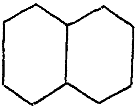


1st Component. 2nd Component.

The product is called an azo-compound and all such substances are intensely coloured. This simple one is yellow. But it is not necessary to start with benzene itself, very many more complex derivatives may be employed; similarly for the second component a wide variety is available. Also by various devices we can introduce two, three or more azo-groups into the molecule and obtain a range of shades from yellow through orange and red to violet, blue, green and black; browns and greys are also feasible. Some of the most widely used first and second components are derived from the coal tar hydrocarbon naphthalene, $C_{10}H_8$, which is a kind of double-barrelled benzene:

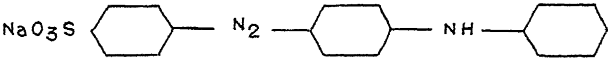


OR



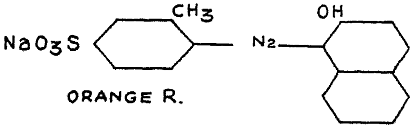
NAPHTHALENE

Tens of thousands of combinations have undoubtedly been made with the aid of this general reaction and of these only a few have been found to possess desirable technical qualities. We may digress here to reflect on the significant fact that the Patent Offices of the world's governments accept specifications couched in the language of the molecular structure theory, the validity of which is also never questioned in Patent Law litigation. Perhaps, inverting Belloc's line, we should exclaim: Oh! let us ever, ever doubt what all the world is sure about. The formulæ of some azo-dyestuffs are annexed in order to give an idea of the wide range.



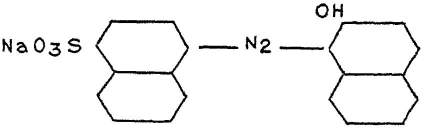
ORANGE IV   YELLOW DYE FOR WOOL & SILK

In this and other cases the SO_3Na group confers the property of solubility in water.

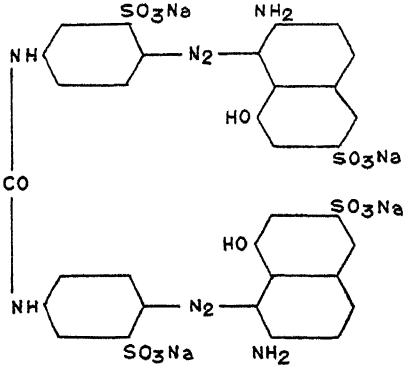


ORANGE R.

ORANGE DYE FOR
WOOL & SILK

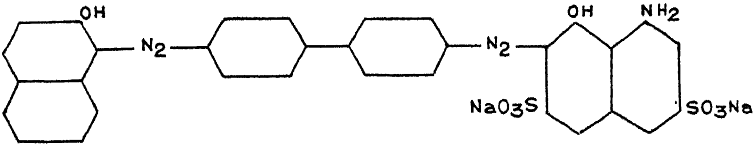


FAST RED A.   RED DYE FOR WOOL
SILK, JUTE OR PAPER.

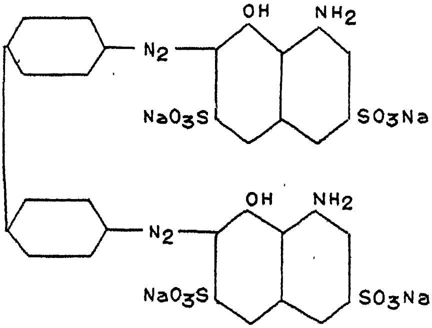


Chlorazol Fast Pink.

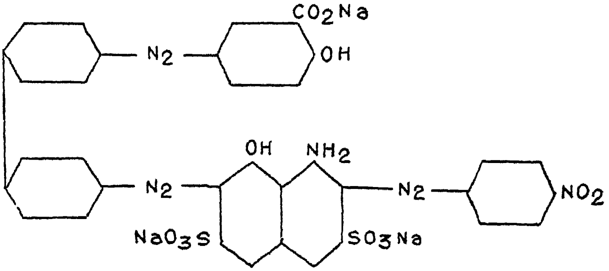
Dyes cotton in bright pink shades.



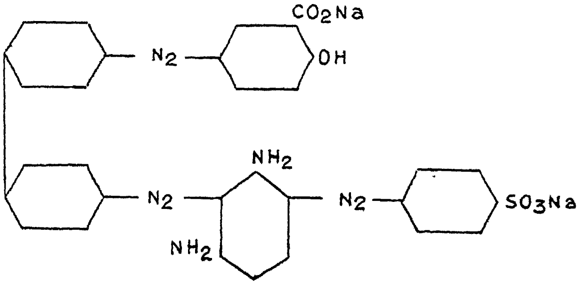
Chlorazol Violet. (Violet cotton dye)



Chlorazol Blue (Blue cotton dye).



Chlorazol Green. (Green cotton dye).



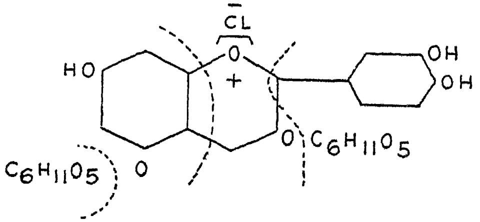
Chlorazol Brown. (Brown cotton dye).

These examples are selected in order to illustrate the effect of increasing molecular complexity on the colour. Blacks are very deep greens or blues and are still more complex in constitution.

As a third example we may turn to the anthocyanin pigments of plants, the colouring matters responsible for the red, violet and blue colours of flowers and blossoms and isolated therefrom by Willstätter. Unlike the azo-dyes, these have no technical value, but they are of considerable scientific interest. One of the more widely distributed is cyanin found in the blue cornflower, the red rose, or the bluish red dahlia. It may be a matter of surprise that one and the same pigment should be responsible for so many hues, but the fact is that the actual colour of a flower is dependent on many factors of which the chief is admittedly the nature of the anthocyanin. In addition, the state of acidity or alkalinity of the cell-sap and the presence or absence of substances combining with the colouring matter are operative. The pigments are indicators; thus cyanin is red in acid solution and blue in alkaline solution. This fact has long been known to children in Yorkshire who make pink bluebells by placing the blue flowers in an anthill. The formic acid produced by the ants effects the transformation. Robert Boyle wrote as follows in 1664:—

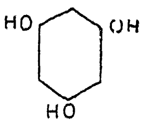
"Take good Syrrup of Violets, Impregnated with the Tincture of the flowers, drop a little of it upon a White Paper . . . and in this Liquor let fall two or three drops of Spirit either of Salt or Vinegar, or almost any other eminently Acid Liquor, and upon the Mixture of these you shall find the Syrrup immediately turn'd Red. But to improve the Experiment . . . etc."

The analytical evidence was interpreted to show that cyanin (as chloride) should be represented by the expression

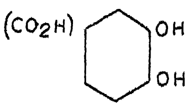


Cyanin chloride.

in which the left-hand and right-hand rings are benzene nuclei. The middle ring is a salt-forming group, somewhat similarly constituted to a benzene ring but in which an oxygen atom replaces a CH group. The dotted lines show the points of cleavage in the analytical degradations and the fragments obtained are the known substances.



$C_6H_{12}O_6$
(2 mols)



The $C_6H_{11}O_5$ groups represent residues of the sugar glucose, $C_6H_{12}O_6$. This has been independently synthesised and its constitution* is shown side by side with that of galactose, a sugar obtained by breaking up the lactose of milk. The asterisked oxygen atom is the one that forms the link to the rest of the cyanin structure.

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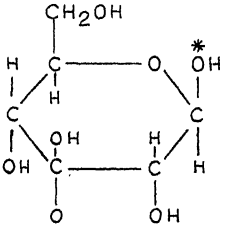
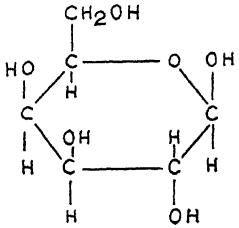
* The outcome of many investigations among which may be mentioned those of Kiliani, E. Fischer, Tollens, E. F. Armstrong, Haworth and Hirst.

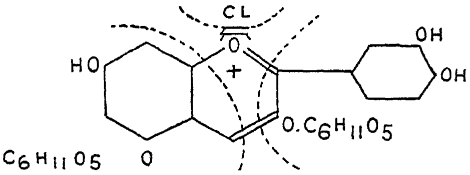


Glucose.

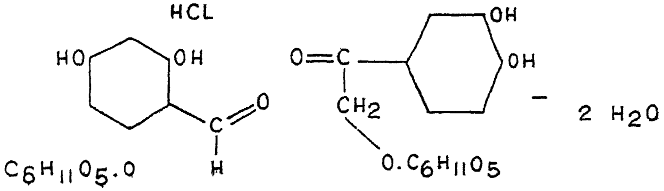


Galactose.

These two expressions are examples of space-isomerism rather than of structural isomerism, and if we assume that the ring lies perpendicular to the plane of the paper it makes a difference whether we place the OH groups above or below. The exact configuration of all the simple sugars has been determined by Emil Fischer, one of the greatest of organic chemists, and the number that is known corresponds with the theoretical requirements. The general reaction used for the synthesis of the various anthocyanins involves union of three parts of the molecule as shown in the formula



(The signs + and − show electrical charges; oxygen is here tervalent.)
and the three components combined were—



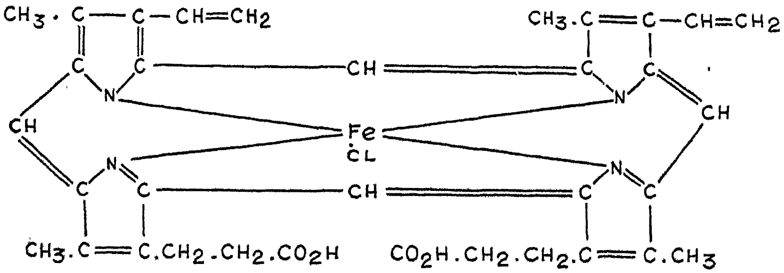
→ Cyanin Chloride

The reaction involved the formation of cyanin chloride and two molecules of water.

Naturally the chief difficulty was the synthesis, by unambiguous methods, of the two larger components, but a discussion of this matter would necessarily introduce highly technical considerations.

It will be observed that the analytical stage of the investigation was entirely distinct from the synthetical. By means of degradations and comparisons the position and relations of each one of the seventy-five atoms in the molecule had been established. The result was embodied in the constitutional *formula* but *specimens* of the pigment from natural sources were, of course, always available for comparison. We then proceeded to build up the molecular edifice step by step taking care at each stage that the bricks went in the right places. The final result was the production of a specimen of artificial cyanin indistinguishable in all respects from the natural material. We are entitled to regard this result as a proof of the validity of the analysis and of the conclusions based on it, but surely it is more than this. It is a justification of the theoretical system itself and carries a conviction that the molecular structures are real things characterising the species.

Perhaps the most striking achievement of synthetic chemistry is the production in the laboratory of the prosthetic group of the blood pigment, the molecular structure of which is shown in the expression



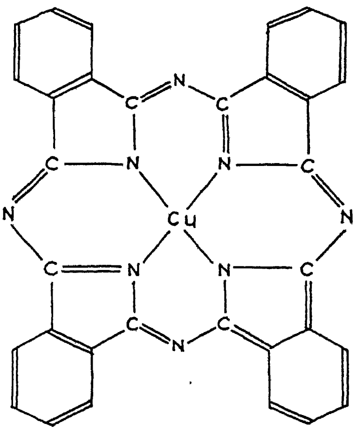
Haemin Chloride.

The details need not be discussed, but once again the combination of analytical and synthetical evidence fixes the position of each atom in the molecule. Professor Hans Fischer to whom we are indebted for this wonderful work is now engaged in elaborating the even more complex molecule of chlorophyll which is built on similar lines.

The azo-dyes have no natural analogues, unless we regard the carotinoids as such, but the technical analogues of the anthocyanins, the beautiful fluoresceins and rhodamines were known before the anthocyanins were isolated and purified.

Until recently technical analogues of the blood pigment and chlorophyll were unknown, but the work of R. P. Linstead, in association with the Research Departments of Imperial Chemical Industries Limited, has disclosed the existence of a valuable blue pigment closely resembling haemin in constitution and yet even more stable and obtainable from quite cheap materials. This is termed phthalocyanine and its discovery was due to the observation of a blue colouring matter obtained in small quantity as a by-product in a routine manufacturing process. The way in which this was followed up affords an excellent example of co-operation between academic workers and an industrial organisation.

The constitution of copper phthalocyanine is shown below; it represents a flat, disc-shaped, molecule which J. M. Robertson has fully analysed by X-ray methods. Indeed, this complex molecule is said to give up all its secrets under such examination, and to be better known as the result of purely physical investigations, than almost any other substance. The electron distribution diagram of nickel phthalocyanine worked out by complete Fourier analysis of the X-ray reflection data is worthy of the closest study (Fig. 1). It is the nearest approach to seeing the chemical molecule which we are likely to achieve for some time to come.



Copper Phthalocyanine.

Finally the difficulty of the problems of the future may now seem appalling, but I am convinced that they will be solved in due course just as present-day achievements go far beyond expectations of thirty years ago. The more complex substances occurring in plants and animals are apparently easily formed enough in the organism and the most hopeful line would appear to be the study and imitation of these natural processes. Astbury and also Wrinch have already discerned signs of order among the proteins and Fig. 2 shows Wrinch's idea of the insulin molecule (M, 37000) in outline. It represents a hollow octahedron and each small solid hexagon represents a number of amino-acid units. The whole structure, stated to be based on mathematical group theory, gives almost exactly the distance between the planes in the insulin crystal that is demanded by X-ray data.* Whether such a conception proves to be correct in detail or not, the conviction is growing that the proteins and other substances of very high molecular weight are constructed on an ordered plan. Despair is only permissible when no fresh light appears on the horizon, and although the molecular architects of the future will have to adopt new methods, there can be little doubt that they will be as successful as those of the epoch that has been the subject of this discourse.

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* Further X-ray investigations by D. M. Crowfoot, published since the delivery of this lecture, show that the detailed structure of insulin does not conform to the Wrinch model which, however, retains its value as a suggestive idea and as a focus for discussion.

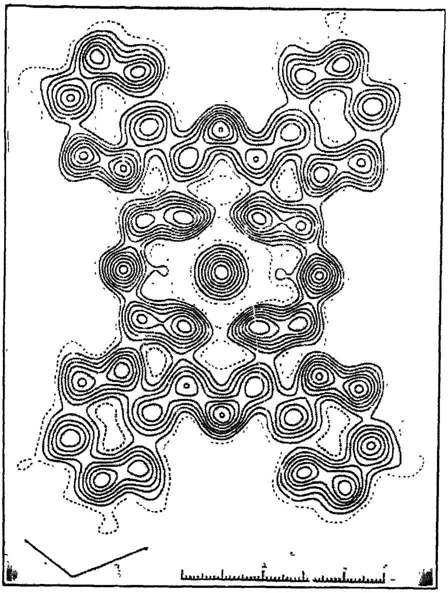


Fig. 1.

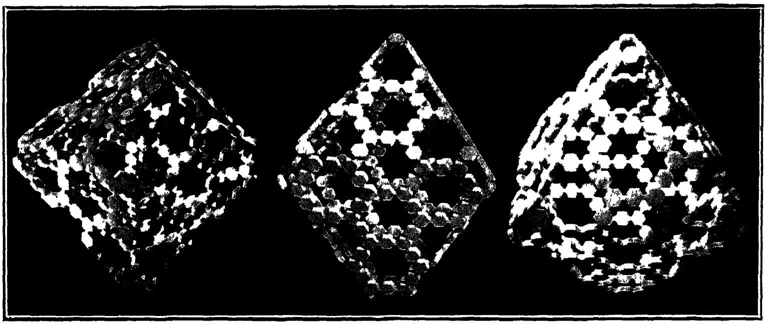


Fig. 2.

ROMAN OBJECTS OF COPPER AND IRON FROM THE NORTH OF ENGLAND.

By

J. A. SMYTHE, Ph.D., D.Sc.

This report deals mainly with the examination of copper alloys which have been unearthed in the neighbourhood of Hadrian's Wall. Many of them come from the old excavations at Corbridge (Corstopitum) which began in the year 1909; these have not hitherto been examined.[1] The rest were discovered during the more recent investigations of Mr. E. B. Birley and Mr. I. A. Richmond at Benwell (Condercum), Housesteads (Borcovicus) and Chesterholm (Vindolana). Besides alloys of copper, there were many found of iron, lead and tin. Those of lead and tin are being examined as part of a wider study of these metals in Roman times and will be described later. Those of iron, as well as a few non-metallic remains, will be briefly dealt with in this paper after copper.

COPPER ALLOYS.

Metallic copper, apparently unalloyed, has only been met with in two cases. It forms the material of two insets, one in the shape of the letter C, the other of a flying bird, in an iron table knife from Benwell. From the metallographic structure of the metal, it is evident that the copper has been beaten into die-like cavities in the iron, then annealed and hammered again until the metal was cold. The other example is a soldier's button from Housesteads, which was found on analysis to contain 99 per cent. of copper. This also has been wrought and annealed.

The alloys of copper with tin, lead and zinc are by far the most frequent metal remains. About 250 of these have been investigated metallographically and 27 have been analysed. The analytical results are given in Table 1, the arrangement being that of increasing copper-content. The find-spot and nature of the objects are appended, together with the result of the metallographic examination, in so far as this bears on the shaping of the objects, whether by casting or working.

Composition of the Alloys. Some restriction in the selection of material for analysis has been imposed by various factors, such as the degree of corrosion and the desirability of preservation of certain objects undamaged. Notwithstanding this, it is thought that the samples selected, with one or two exceptions to be mentioned later, are representative of the whole assembly. To prepare them for analysis they were cleaned from scale by filing and grinding. Chemical alteration is, often, deep-seated and some cleaned objects, which appeared to be of sound metal, were found to be brittle and to give a dull, earthy fracture, owing to penetration of the metal by corrosion-products. As a result of this, the total of the metal-constituents determined is usually under 100 per cent. the mean value for the 27 analysed specimens being 98.8 per cent.[2]

The constituents of most of these alloys are copper, tin, lead, zinc, iron and nickel. A trace of silver has been found in some cases where specially sought. As this metal is converted into the insoluble chloride,[3] during the corrosion-process, it is left behind with the tin oxide during the ordinary course of analysis. Tests for arsenic and antimony have been made in some cases where the quantity of available material sufficed, but only traces, at the most, of these metals have been found.

Nickel occurs in practically all the alloys. In the 15 cases where it has been estimated, it ranges from 0.01 to 0.09 per cent averaging 0.035 per cent. Though certainly an original constituent of the copper, its amount does not depend directly on the copper-content of the alloys, a circumstance to be explained either by difference of origin of the copper,[4] or by varying loss of nickel during the corrosion-process. There are indications that both causes have been operative.

Iron is small and variable, but obviously related to the zinc-content. In 8 cases where this is below 4.2 per cent. iron is only present in trace or is absent; in 8 cases where it ranges from 36 to 6 per cent. iron is high and roughly proportional to the amount of zinc. There are but few exceptions in each category. It is apparent, then, that the iron is roughly proportional to the zinc. It is unlikely that the iron has been introduced with the zinc, since the latter metal was unknown to the Romans and its only source was its alloy with copper. The most probable explanation is that the iron is a product of infiltration, having been precipitated from percolating water in some form suitable for preservation by zinc.

In the main these copper alloys can be described as bronzes, i.e. alloys of copper and tin, though few of them correspond to the bronzes in industrial use at the present day. There are

TABLE 1. Analyses of Copper Alloys.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cu	58·50	59·44	60·60	64·10	66·44	74·79	75·37	75·90	77·16	77·40	79·86	80·36	80·70	82·11
Sn	35·82	1·02	9·24	32·97	22·65	12·24	7·91	11·94	2·52	7·71	6·03	5·16	5·24	9·59
Pb	2·19	2·02	29·47	3·30	9·78	6·94	8·95	8·40	10·30	14·01	5·88	3·62	nil.	6·80
Zn	0·23	36·00	tr.	0·26	0·21	2·67	7·14	1·58	9·53	0·21	6·71	9·72	12·17	1·63
Fe	tr.	0·54	nil.	tr.	nil.	tr.	tr.	tr.	0·18	tr.	tr.	0·17	0·31	0·10
Ni	tr.	nil.	tr.	tr.	0·03	0·09	0·05	0·02	0·01	0·02	0·03	0·03	0·03	tr.
	96·74	99·02	99·31	100·63	99·11	96·73	99·42	97·84	99·70	99·35	98·51	99·06	98·45	100·23

	15	16	17	18	19	20	21	22	23	24	25	26	27
Cu	83·40	83·80	84·41	84·60	87·04	87·72	88·00	89·30	90·04	93·40	94·20	94·90	96·40
Sn	0·43	4·64	8·92	1·77	8·63	4·68	9·89	8·08	10·01	3·36	5·96	4·67	2·93
Pb	0·36	nil.	0·32	nil.	tr.	0·09	nil	nil.	n.d.	1·33	n.d.	nil.	nil.
Zn	12·64	10·06	4·19	12·87	2·89	5·98	1·47	tr.	n.d.	0·54	n.d.	tr.	n.d
Fe	0·28	0·11	nil.	0·37	tr.	0·43	tr.	tr.	n.d.	0·22	n.d.	tr.	n.d.
Ni	nil.	0·04	0·04	0·04	tr.	0·04	0·05	tr.	n.d.	tr.	n.d.	0·01	n.d.
	97·11	98·65	97·88	99·65	98·56	98·94	99·41	97.38	100·05	98·85	100·16	99·58	99·33

1. Housesteads. Small cake, cast.
2. Housesteads. Ring 1.5" dia. cast.
3. Benwell. Finger Ring, cast.
4. Benwell. Small cake, cast.
5. Corbridge. Thin plate, cast.
6. Corbridge. Rod of square section, cast.
7. Benwell. Plummet, cast.
8. Corbridge. Ornament, stag's head, cast.
9. Chesterholm. Key, cast.

o. Benwell. Horn-shaped ornament, cast.

11. Corbridge. Ornament, cast.
12. Corbridge. Hairpin, wrought.
13. Corbridge. Round-headed nail, wrought.
14. Benwell. Bowl, cast.
15. Housesteads. Fibula pin, wrought.
16. Corbridge. Staple, wrought.
17. Housesteads. Wire spiral, wrought.
18. Corbridge. Hairpin, wrought.
19. Corbridge. Wire, square section, wrought.
20. Corbridge. Wire, square section, wrought.
21. Housesteads. Tweezers, wrought.
22. Corbridge. Wire, roundish section, wrought.
23. Housesteads. Ornament, wrought.
24. Corbridge. Hairpin, wrought.
25. Housesteads. Unidentified, wrought.
26. Corbridge. Wire, ornamented, wrought.
27. Corbridge. Spring, wrought.

(tr. = trace ; nd. = not determined.)

some, however, which both in composition and in colour are allied more to the brasses, the alloys of copper and zinc, though again differing very considerably from the modern brasses. In these alloys, the zinc exceeds in amount the sum of tin and lead.[5] They are represented in Table 1. by Nos. 2, 12, 13, 15, 16, 18 and 20. Some generalisations derived from the study of the composition of these two groups will now be given, omitting for the moment the first five in the table of analyses.

The Bronzes.

In these the percentage of tin ranges from 2.5 to 12.2 per cent. and it is of interest to observe that in ancient Peruvian[6] bronzes the range is from 2 to 13 per cent. and in Egyptian,[7] 2 to 16 per cent. Tin is unaccompanied by lead in 7 objects and in these the tin varies from 2.9 to 10 per cent. It is evident, therefore, that tin, free from lead, has been used in making the alloys and that its scarcity in the remains associated with the bronzes must be ascribed to some such cause as the disintegrating action of the tin-disease. Alloys of tin containing a few per cents. of lead are not infrequent, from which it would appear that these were not mistaken for pure tin, at any rate by the bronze-makers. These 7 lead-free bronzes along with 2 others containing a small amount of lead (0.3 to 1.3 per cent.) have all been worked, as shown by their microstructure, so that we may infer that the old craftsmen were able to work bronzes with as much as 10 per cent. of tin in them, and that they were careful to debar lead, or to keep the amount of it very small in bronzes which they intended to work.

Lead in quantity is confined to the cast bronzes, of which there are 7, containing up to 14 per cent. of lead. Three of these are high in zinc (6.7, 7.1, 9.5), the rest low in zinc but high in tin (7.7, 9.6, 11.9, 12.2). Zinc is present, often in small amount, in 11 bronzes, absent in 5, and these of the highest copper-content. In those of lower copper-content, there is no simple relationship between the copper and the zinc. It would appear, therefore, that pure copper was used for making the alloys of high copper-content, and that metal containing zinc, some of it probably scrap, was used for the rest, especially for those to be cast.

The Brasses.

There are 6 of these alloys in the table of analyses and many others have been examined metallographically. They always show the wrought structure and they are the favoured material for the making of pins and small appliances like tweezers, where springiness is required. A good deal of wire, evidently used in making these articles, consists also of brass. Generally speaking, brass resists corrosion better than bronze and one frequently finds bronze fibulæ in an advanced stage of destruction by corrosion, with the brass pins in a sound condition, though perhaps rather deeply pitted. The greater corrodibility of the cast alloys has been ascribed to their porosity and heterogeneity,[8] but there are indications that chemical composition is also a factor of considerable importance.

There is a close resemblance in the analyses of the 6 specimens. They contain variable amounts of tin, up to 5 per cent. but little or no lead and the maximum amount of zinc is 12.9 per cent.[9] If the analyses be recalculated in terms of copper and zinc only, then they fall into 3 groups, thus:

Number (Table 1)	13	15	18	12	16	20
Copper ...	86·9	86·8	86·8	89·2	89·2	93·6
Zinc ...	13·1	13·2	13·2	10·8	10·8	6·4

This rather suggests that there were large stocks of brass available for making certain articles and that the composition of these could be controlled so as to correspond to the modern gilding metal (copper 87, zinc 13). It is of interest that Nos. 13 and 18 are from Corbridge and 15 from Housesteads and that the tin-content of the three varies considerably. This may imply distribution of the standard brass from one centre of manufacture. The subsequent additions of tin and lead to the standard brass seems to be without any rational foundation.

Outstanding Alloys.

There are, as already mentioned, 5 alloys which differ considerably from the general run of bronzes and brasses. They are all cast and their analyses are given in Table 1. Nos. 1 to 5.

No. 2 is like a modern brass of the free-cutting type in composition and it has the structure of a cast 60/40 brass. It is a slender ring, 1½ inches in diameter, with a small, internal casting pipe. It may be of comparatively recent age, though it has obviously been buried for some time, since it is strongly corroded and, in micro-section, shows that a good deal of secondary copper has been deposited on the beta-constituent. Zinc is exceptionally high for a Roman alloy.[10] (Plate 1, No. 1.)

Nos. 1 and 4 (Plate 1, No. 2) are close in composition and micro-structure to speculum metal. Both are in the form of small rounded cakes, weighing a few grams, one is from Housesteads, the other from Benwell. No. 5 from Corbridge is in the form of thin plates, with a casting pattern of fine parallel lines and probably fragments of a mirror. It is distinguished from the others by its high lead-content, which is well shown in the micrograph (Plate 5, No. 17). The consideration of these three alloys suggests that economy in the use of tin, by substituting part of it by lead, was a factor of importance to the makers, for the sum of lead and tin does not differ much in the three cases (viz. 38, 36 and 32 per cent.) and is close to the modern speculum-ratio, viz. 34 per cent.[11] It is also of interest that each alloy contains 0.2 per cent. of zinc, probably added, as brass, for de-oxidising purposes.

Finally, alloy No. 3, a finger-ring from Benwell, is distinguished by its very large lead-content (29.5 per cent.). Oddly enough it resembles in composition some bearing alloys, of comparatively recent introduction into industry, known as the plastic bronzes.[12] One of the chief difficulties in the use of such an alloy is to hinder the lead from separating out, and the micro-section showed that this difficulty had been very successfully overcome. It may be observed that the sum of tin and lead, 38.7 per cent., is almost the same as in alloy No. 1, but this must be regarded as coincidence only, for the alloy under discussion has none of the properties of a speculum metal. It is simpler and more reasonable to assume that this alloy has been made from a straight 87/13 bronze by alloying 70 parts by weight of this with 30 of lead.

Metallography of the Alloys.

The micro-structure of the alloys yields much information as to their composition and history and since only a small surface is needed for the preparation of the section many objects, the preservation of which is desirable, can be studied by this method. It may be permissible to mention here that alloys of copper and tin, when suitably prepared and etched, are cored in the cast condition; that under ordinary conditions of casting of such small objects, only one constituent, the *alpha* solid solution, is shown when the tin-content is below ca. 8 per cent., that a second constituent, the *alpha delta* eutectoid appears when the tin exceeds this limit and that the proportion of this increases with the tin; that adequate annealing removes coring and when this follows cold-working, the homogenisation and recrystallisation of the metal, with the formation of twinned crystals is effected.[13] Lead is not soluble in copper and thus separates, partly in drops, easily visible on the polished, but unetched surface. Zinc, in the quantities we have to deal with, forms an *alpha* solid solution, similar to that derived from tin.

The results of the metallographic study of the alloys, now to be described, are based on the study of 250 micro-sections. In only few cases, owing to corrosion or indeterminate structure, was it not possible to infer anything positive about composition or treatment of the alloys. 237 of them were satisfactory in this respect and of these 144 (61 per cent.) are cast and 93 (39 per cent.) wrought, the latter group containing all the obvious brasses. Of the cast alloys 25 per cent. are of *alpha* bronze, of which 5 per cent. are leaded and 20 per cent. free from lead, and the remaining 75 per cent. are *alpha delta* bronzes, of which 45 per cent. are leaded and 30 per cent. not leaded. Otherwise expressed, half of the cast bronzes are leaded and in this group there are 9 times more with tin over 8 per cent. than of those whose tin-content is below that figure. One may thus infer that the usual working practice was to add lead to bronze of relatively high tin-content in order to get an alloy of good liquidity suitable for common castings.

For the visual estimation of tin in the *alpha delta* (eutectoid) bronzes, 87 micro-sections were suitable. The extreme values were 8 and 15 per cent. the average 10 per cent. Eleven of these were analysed, the corresponding values being; extremes 7.7 and 12.2, average 9.5. The correspondence is quite satisfactory and it is evident that the metal selected for general casting purposes was roughly a 90/10 bronze (gun-metal) to which more or less lead was added in order to improve its running properties. For better castings, probably, a bronze richer in copper was used; additions of lead, when made, were small in quantity, but generally lead was omitted. These *alpha* bronzes, especially the leadless ones, were also used when the alloy had to be wrought. In the best, and undoubtedly most expensive, metal for wrought objects, the quantity of tin is further reduced, considerable additions of zinc are made, and lead is almost completely dispensed with.

The purposes for which the cast and wrought alloys were used is summarised below.

	Cast.	Wrought.
Personal. Brooches	32	6
Brooch- and Hair-pins	1	14
Finger Rings	10	7
Tweezers	—	4
Ornamental. Various	30	7
Discs (usually convex)	—	16
Harness Trappings	18	3
? Split Rings	4	7
Domestic. Bowls, Spoons, Pans, Keys, etc.	23	—
Industrial. Ingots, Weights, Plummets, etc.	12	—
Nails, Staples	2	6
Wire	2	20
Unidentified and Scrap	10	3
Total	144	93

In some of these groups there is considerable latitude in the selection of material. Thus, in brooches of the fibula type, about half are made of *alpha* bronze, some wrought, most cast (and a few of these leaded), the remainder are eutectoid alloys, partly leaded and partly lead-free. Similarly with the rings, half of which are of wrought *alpha* bronze and half cast; of the latter, one third are leaded.

From many of the photo-micrographs of the cast alloys reproduced in the accompanying plates it will be apparent that the structures are identical with those of recently-made alloys of similar composition. It is now a commonplace in these studies that diffusion, in alloys like bronze, is virtually inoperative at the ordinary temperature; so that structures, such as coring, arising from non-equilibrium conditions persist for ages unchanged.[14] Modifications of the typical structures of the simple binary alloys of copper and tin, produced by the presence in varying quantities of lead and zinc, are observable but not easy to evaluate. These additions effect the appearance of the eutectoid, tending to make it less heterogeneous, and either alter the stage, with respect to tin-content, at which it appears, or increase the amount normal to the straight alloys of the same tin-content (Plate 2, Nos. 5 and 6). Both points are complicated somewhat by variation in casting conditions and the combined effect of the two factors is to introduce added uncertainty in the visual estimation of tin.

A very characteristic feature of the wrought alloys is the lack of completeness of the structural changes which accompany cold-working followed by annealing. The micrograph Plate 2, No. 7, shows, perhaps, as good an example as has been encountered of the recrystallisation of the metal, with the development of sharp-edged grains and twinned crystals; but, even here, there are still traces of the coring of the original slab-casting visible in the form of broad bands, alternately light and dark. In most cases, however, the homogenisation of the metal has not reached such an advanced stage; partial recrystallisation is superimposed either on undistorted coring (Plate 6, No. 20, and Plate 7, No. 21) or the cores of the original casting are distorted in varying degree, sometimes being drawn out (along with the non-metallic inclusions) in parallel bands (Plate 2, No. 8 and Plate 3, No. 9), at other times torn into lenticular patches (Plate 6, No. 19). Recrystallisation may be arrested at any stage. When rudimentary, it is often localised in areas defined by the residual coring, where, presumably, the complex factors of composition, degree of cold-working, temperature and duration of annealing have been conjointly most favourable. This is well shown in Plate 7, No. 22. The full development of such structures usually requires careful etching-treatment and they may easily be overlooked.

These twofold structures are the result of the methods of working, in which small portions of cast metal are heated, perhaps barely to redness, withdrawn from the fire and hammered on a cold anvil, the temperature falling rapidly into the region of cold work. Repetition of this procedure many times brings about a certain degree of annealing, never complete, and often the object is left in the cold-worked condition, of which there is evidence in the striation of the grains and the distortion of the twinned crystals. Carpenter[15] has proved experimentally that the temperature of an ancient Egyptian axe-head, containing 97.4 per cent. of copper and 0.5 of arsenic, in a structural condition similar to some of the objects under consideration, has not exceeded 800°C; and Mathewson[16] has determined the relation between temperature and time required for complete homogenisation of cast 95/5 bronze; this is:—4 to 5 hours at 625°, 3 hours at 750°, 5 to 8 minutes at 850° C. In the light of these (and other) results, it is probable that these Roman alloys were not heated above 700° C and were seldom retained long at this temperature.

Several examples of composite metal have been met with and some of these are illustrated in the micrographs. Plate 3, No. 10 shows a small inclusion of wrought *alpha* bronze (or brass) in a cast leaded bronze, the junction between these being imperfect. In No. 11 is shown a perfectly-fused weld between wrought *alpha* bronze and cast bronze extremely rich in tin. Such examples prove that the scrap metal industry is of ancient origin.[17]

Some points concerning working methods deserve, perhaps, passing mention. Hinge pins of bronze seal boxes are made of iron; those which secure the spring of fibula-pins are of iron, brass, or bronze and, in the last case, the metal is usually wrought, whilst that of the brooch itself may be cast. (Plate 3, No. 12.) In one case, an iron rivet seemed to be set in a bronze sleeve. A section cut through an ornamental stud in a fibula showed that the fibula had been drilled to take the inset, the evidence being the dragging out of the cores of the cast metal of the fibula, roughly tangential to the edge of the hole.

Some of a large number of curved, circular discs, chiefly of wrought brass, have their convex cavities filled with soft lead. The purpose of these is not known.

Repetition work and the transport of commodities is indicated by the identity of two rather intricate, ornamental castings in bronze, found at Corbridge and Housesteads.

Finally, an ornamental stylus handle of bronze still contained a core of baked clay and the missing stylus had apparently been secured with lead, now completely converted into the basic carbonate.

Graphic Representation of the Composition of the Alloys.

The chemical analyses, with the exception of No. 2, Table 1, the antiquity of which is uncertain (as already noted) are plotted in Fig. 1. The abscissæ represent copper-content and tin, lead and zinc are plotted, cumulatively, as ordinates. The brasses are similarly shown in the inset diagram. The area between the tin and the lead ordinates is shaded in order to bring out the relationships more clearly, and the regions of

cast and wrought alloys, as determined from the examination of micro-sections, are shown.

This diagram serves to summarise a good deal of the evidence already presented and brings out clearly the following conclusions.

1. In the bronzes, the cast alloys have a range of 24 per cent. of copper, i.e. between 58 and 82 per cent; from 82 to the maximum 97 per cent. the alloys are all wrought.
2. Lead in quantity is only present in the cast bronzes and ordinarily averages 9 per cent.; in most of the wrought bronzes it is absent, in the remainder, present in small quantity.
3. Zinc, in the bronzes, is practically restricted to a range of copper-content of 13 per cent. viz. between 75 and 88 and averages 3.5 per cent.; it is very small both above and below these limits.
4. The brasses are all wrought and are confined within the limits of copper-content 80 and 88, the upper limit of which coincides with that of the zincy bronzes. The zinc-content averages 12 per cent.; tin is low (average 3.6) and the amount of lead almost negligible.

The recognition of these relationships cannot but impress one with the control of composition which the Romans exercised in the making of their alloys. This is particularly remarkable in the case of the zinc-constituent, since the metal, as such, was unknown to them. In the technique of alloy-making, their skill would appear to be comparable with that displayed in the casting and working of the alloys.

Corrosion of the Copper Alloys.

The degree of corrosion of the alloys varies from what is little more than a thick patina to complete conversion of the metal-constituents into oxidised compounds. The extent of the change, as well as the colour and surface-characteristics (roughness or smoothness) of the patina or crust, depends to some extent on chemical composition, but it is not possible to state the matter more definitely at present. The wrought alloys, as already mentioned, withstand corrosion better than the cast alloys. The grain-boundaries and twinning planes are most susceptible to change, and this intergranular corrosion has been recognised as a sure means of distinguishing the spurious from the true antique.[18] In the cast alloys the areas rich in tin, between the dendritic arms of the primary crystals, are most affected. Corroded areas are black in unetched micro-sections and generally undistinguishable from lead, but the tendency of the latter to separate in globules establishes a useful difference. The structure of such corroded alloys can usually be inferred from the polished surface, without etching. (Plate 4, Nos. 13 and 14.)

Secondary copper, that is copper precipitated from the solution of its salts formed in the corrosion-process, is often observable and, in heterogeneous alloys, is usually restricted to the tin-rich or zinc-rich constituents. There is a suspicion in some sections that it is also deposited on lead, since it occurs in rounded patches, but it has not been possible to prove this definitely.

Much work with a technical end in view has been done, in recent years, on the atmospheric corrosion of copper and its alloys.[19] It has been shown that the patina developed on copper in towns consists largely of the basic sulphate, and near the sea of the basic chloride. After a time the composition approximates to that of the minerals brochantite, $4CuO.SO_3.3H_2O$ and atacamite, $3CuO.CuCl_2.3H_2O$, and the carbonate, when formed, to malachite, $2CuO.CO_2.H_2O$. These minerals are derived from cuprous oxide (cuprite, Cu_2O) and possibly in some cases nantockite, $CuCl$,[20] the latter, formed under chloridising conditions, being readily oxidised to cuprite and cupric chloride.[21] When lead is present it may be converted into caledonite, $4PbO.2CuO.SO_3.3H_2O$, or perhaps more likely into the sulphate, anglesite or the basic carbonate. Tin apparently passes into the hydrated di-oxide, zinc and nickel[22] are removed almost entirely as soluble salts.

When corroded specimens containing a core of metal are sectioned and polished they show, under oblique illumination, a zone of red cuprite surrounding the metal, and this zone is enveloped by green malachite or atacamite, spotted with white, woolly patches of the oxidised compounds of lead and tin. Though visually clear under the microscope, by reason of the different colours, such structures do not lend themselves to photographic reproduction. By careful grinding of such specimens, samples of the red product have been obtained which have been proved by analysis to contain as much as 56 per cent. of cuprous oxide.

In order to study the effect of the corrosion-process, carried to its completion, a large number of objects, after ordinary cleaning to remove dirt, were filed carefully, so as to detach the outside layer, as free as possible from cuprite and metal. Thus was obtained a light green powder of the following composition:—

SiO_2	3.55
Fe_2O_3	1.74
CaO	0.70
CuO	36.08
SnO	18.42
PbO	18.91
ZnO	1.41
H_2O	11.05
CO_2	5.42
P_2O_5	0.46
SO_3	1.11
Cl	1.24
Less O for Cl	0.27
	99.82

Traces were found of silver and magnesia; proved absent: gold, bismuth, cadmuim, arsenic, antimony, nickel and sulphur (as sulphide). Some of the copper is present as cuprous oxide and some of the iron is in the ferrous condition, but the accuracy. Tin is entirely in the stannic condition.

In allocating basic to acidic oxides the following assumptions are made:—

1. Phosphoric acid is present as the hydrated ferrous phosphate, vivianite,[23] $3FeO.P_2O_5.8H_2O$, the remainder of the iron being in one of the forms of hydrated ferric oxide, like limonite, $2Fe_2O_3.3H_2O$.

2. Lime exists as gypsum, $CaSO_4.2H_2O$, the excess of sulphuric acid being fixed as the sulphate of lead.

3. Chlorine is in the form of atacamite, carbonic acid as malachite and the remaining metallic oxides are hydrated to the mono-hydrate stage, since this uses up almost all the available water.

The proximate composition thus works out to:

SiO_2	3.55
$3\ FeO,\ P_2O_5,\ 8\ H_2O$	1.63
$2\ Fe_2O_3,\ 3\ H_2O$	1.13
$CaSO_4,\ 2\ H_2O$	2.15
$CuCl_2.\ 3\ CuO.\ 3\ H_2O$	7.47
$2\ CuO,\ CO_2,\ H_2O$	27.25
$CuO,\ H_2O$	13.36
$SnO_2,\ H_2O$	20.62
$PbO,\ H_2O$	0.42
$PbSO_4$	20.10
$ZnO,\ H_2O$	1.72
H_2O	0.42
	99.82

On this interpretation the corrosion-products contain 9 per cent. of adventitious matter (sand, infiltrated iron and calcium salts, moisture) and 91 per cent. of oxidised compounds and salts of the four constituent metals; of these, 35 per cent. are present as carbonates, chlorides and sulphates and 56 per cent. as hydrated oxides. Viewing the matter otherwise, the metals have fixed in their corrosion-products 12.8 per cent. of oxygen and 8.2 per cent. of acidic radicles, three-quarters of the latter being carbon dioxide and one quarter the radicles of phosphoric, sulphuric and hydrochloric acids. Oxidation, with its accompanying hydration of the oxides, thus exceeds considerably salt-formation.

The high proportions of chloride and sulphate in the corrosion-products is interesting in so far as analyses, made many years ago, of the soil produced by the weathering of the dolerite at Housesteads, whence many of the specimens came, showed the absence of these radicles. Opportunity was taken of the excavations at the camp in 1933 to collect a large sample of soil, which has recently been turned out. This was found to contain P_2O_5, O.52; SO_3., 0.044; Cl, 0.0025 p.c.

The chlorine is very low in this.[24] Its high content in the corrosions must be ascribed, in part at least, to the insolubility of the atacamite, but it seems possible that it may mark former pollution of the soil by sewage.

One more point seems worthy of mention. The varying degree of chemical attack of corroding agents on the metals and of solubility of the resulting products of reaction leads to a very different proportion of the four metals in the alloys and their corrosion-products. If we take the mean of the analysed alloys as representing substantially the composition of the metal from which the corrosion-products are derived and calculate to 100 per cent. the composition of each in terms of the four constituent metals, then we find:

Mean of Alloys.		Corrosion Products.
Cu	82.0	46.5
Zn	3.9	1.8
Pb	4.3	28.3
Sn	9.8	23.4
	100.0	100.0

As the result of the corrosion-process, then, copper and zinc are reduced by half, tin increases more than twofold and lead more than sixfold. Such relationships will naturally vary greatly according to conditions, so that the deduction (often attempted) of the composition of an alloy, from that of a badly corroded specimen must be fraught with the greatest uncertainty.

ALLOYS OF COPPER AND SILVER.

The number of these alloys is small and the quantity at disposal was never sufficient for a satisfactory analysis. From such analyses as could be made and occasionally from their micro-structures it would appear that they fall into two groups containing, respectively, 80 and 20 per cent. of silver. Most of them contain gold, the silver is partly converted into chloride and in some cases the copper appears to have been added in the form of brass.

The 80/20 Alloys. There are three examples in this group.

1. A perfectly-shaped letter A, one inch long and not much thicker than writing paper; from Corbridge. It contains both silver and copper and the micro-structure is that of the 80/20 alloy.

2. A piece of wire, from Corbridge, obviously worked since the non-metallic constituents are drawn out parallel to the length of the wire. Analysis gave: Ag, 76.9; AgCl, 0.7; Cu, 18.6; Zn, 1.6, Total, 97.8 per cent. Some gold and lead are also present. The etched micro-structure was obscure.

3. A piece of thick wire or thin rod 0.1 inch in diameter, from Corbridge. Though greatly weathered the micro-structure was tolerably clear and was that of the 80/20 alloy. The analysis is: Ag, 70.3; AgCl, 15.9; Cu, 6.6; Zn, 1.6; FeCO$_3$, 0.4; CaCO$_3$, 0.5, Total, 95.3 per cent. Gold is present in strong trace. To reconcile this composition with the micro-structure it must be assumed that much of the copper in the alloy has been leached out, and the presence of the infiltrated carbonates is an indication that there has been extensive percolation by water. It will be noted that 2 and 3 both contain zinc.

The 50/50 Alloys. There are two examples in this group.

1. A small ornamental pendent from Brough, Westmorland. The micro-structure is that of the 50/50 alloy and the S.G. 9.39 is close to that calculated for this alloy, viz. 9.56. This specimen, and also the next below are of a silvery colour. The removal, by leaching, of copper from the surface of such alloys has been commented on by Garland and Bannister.[25] On

polishing, they acquire the colour of silver or steel and the true coppery tint of the alloy is only disclosed by filing.

2. An ornament from Housesteads rather badly corroded. A very small amount of filings gave on analysis: Ag, 41 ; Cu, 36 p.c. Also present were silver chloride, gold, lead, zinc and the carbonates of iron and calcium. The micro-structure is extremely clear (Plate 4, No. 15) and is that of the 50/50 silver-copper alloy, with the qualification that the eutectic areas do not show the copper-rich constituent, which has evidently been leached out.

In addition to these alloys, there is a small sample of thin sheet of purplish colour from Housesteads which appears to contain only silver and gold, the silver largely converted into chloride. Its composition is: Ag, 30.6 ; AgCl, 65.4 ; Au, 0.6, Total, 96.6 p.c. It may further be mentioned that there are several examples of gilt bronze ornaments (brooches and rings). All are much corroded and the gold could usually be scaled off with ease. This gold is of paper-thickness.[26]

IRON.

A large number of iron objects from all the camps on the wall has been examined. They include picks, chisels, chains, chain mail, bill hooks, sickles, spear heads, knives, rings and nails. Some are entirely rusted and the surrounding soil and grit cemented into a compact conglomerate by ferric oxide. Most, however, contain a core, more or less substantial, of the metal and in some cases, notably that of a finger-ring of very pure iron, the preservation of the metal is remarkable.

Altogether, some 50 micro-sections of the metal have been studied. A number show pure iron, without trace of carbide, containing only some streaks of cinder or slag. (Plate 4, No. 16.) Some sandal-nails were of fairly uniform high carbon steel (about 0.7 per cent. of carbon) but most of the specimens show alternate bands and lenticular patches of iron and mild steel, a necessary consequence of the method of smelting and working.[27] Mild steels are often devoid of pearlite, but show cementite in wisps or streaks at the grain-boundaries of the ferrite, the result of prolonged forging at a comparatively low temperature. In a few cases only, in the medium steels, there is a coarsening of the pearlite and something approaching a Widmanstätten structure, indicative of a high temperature.

Quenching structures have only been observed in one object, that of a chisel from Chesterholm.[28] The main interest attaching to this, apart from the survival of a non-equilibrium structure for close on 20 centuries, is the proof that the artificer knew of the method of hardening by quenching, but was either ignorant of the need for preliminary carburisation, or neglected the step.

A few observations relating to the working of iron have been made. Sockets for various tools and weapons are made by bending the flanged end of the object and the wooden shaft is secured by nails through the socket. A roadman's pick gave evidence that its socket was drifted and also that a broken point had been mended by welding on a piece of metal about 2 inches in size. The Benwell table knife with the copper insets, already mentioned, did not show signs of welding at the tang. A strip of iron from Bankshead (No. 52 Mile Castle) gave evidence of having been welded in two places, close together.

Corrosion of Iron. Two examples have been examined in some detail, one of ordinary rusting, the other of corrosion under conditions rather of a carbonating than an oxidising nature.

Large masses of chain mail from Chesterholm, the constituent rings of which were 0.3 inch in diameter, proved on close examination to be almost free from metal, only one minute piece, of pin-head size being found. This was sufficient, however, to establish by metallographic methods that the metal was a very mild steel. The rust was found to be strongly magnetic. Accordingly a sample was carefully cleaned, crushed to pass the 80-mesh sieve, the powder thoroughly washed and then magnetically concentrated. Analyses of the whole material A, the hard magnetic concentrate B, and the non-magnetic residue C were made (upper part of the following table).

	A	B	C
SiO_2	3.10	0.50	4.58
Al_2O_3	nil.	nil.	nil.
FeO	15.54	29.79	8.61
Fe_2O_3	72.30	66.64	73.26
MgO	tr.	nil.	tr.
CaO	0.30	0.20	0.30
CO_2	nil.	nil.	nil
P_2O_5	0.46	0.19	0.60
$H_2O(—)$	1.85	0.45	3.48
$H_2O(+)$	6.25	2.50	9.10
	99.80	100.27	99.93

SiO_2	3.10	0.50	4.58
Apatite, $3\ CaO.P_2O_5$	0.55	0.37	0.55
Vivianite, $3\ FeO.P_2O_5.8\ H_2O$	0.53	0.05	0.87
Magnetite, Fe_3O_4	49.73	95.98	27.17
Limonite, $2\ Fe_2O_3.3\ H_2O$	44.42	0.51	63.72
H_2O	1.47	2.86	3.04
	99.80	100.27	99.93

Assuming the lime to have the first claim on the phosphoric acid and the remainder of the latter to form vivianite, the residual ferrous oxide to exist as magnetite and the unclaimed ferric oxide as its hydrate, limonite, then the compound-constituents are as in the lower part of the table.

Of particular interest in these results is the proof that the rust, after centuries of oxidising conditions, still contains 50 p.c. of magnetic oxide of iron.[29] Polished sections of the rings show a core of dark, compact magnetite, so that one may infer that oxidation of the ferrous oxide, initially formed from the iron, led to the formation of the magnetic oxide which was then slowly converted, from the outside inwards (presumably after the disappearance of the metallic iron) into ferric oxide. It will be noted that the vivianite is greatly concentrated in the non-magnetic fraction, whereas the apatite suffers but little change. This suggests constant accession, throughout the whole period, of percolating water containing calcium phosphate, some of which is deposited as apatite and the remainder slowly converted by double decomposition with magnetite into vivianite, with resulting liberation of ferric oxide and lime. The latter is carried away in solution as bicarbonate. On this view the limonite is not a direct oxidation-product of magnetite, but results from the reaction between magnetite and calcium phosphate.[30]

A number of objects from the well at Chesterholm were found to be made of very pure iron and to have suffered corrosion of a different kind from that just described. Their surfaces were smooth, the shape of the objects being well preserved and the colour was almost black, with a bluish tinge which developed in intensity on removal from the well. Rusty, wart-like excrescences occurred in some places. The composition of the scale was as follows:

Insol. in acid	6.90
TiO_2	nil.
Al_2O_3	4.04
FeO	37.27
Fe_2O_3	11.58
CaO	3.32
MgO	nil.
CO_2	21.90
P_2O_5	3.13
SO_3	0.19
S	0.32
H_2O	9.05
Less O for S	0.10
Alkalies and Loss	2.40
	100 00

From these figures, the composition in actual components is calculated:

$SiO_2+Al_2O_3$	11.2
$CaSO_4.2\,H_2O$	0.4
$CaCO_3$	5.8
$FeCO_3$	52.4
$3\,FeO.P_2O_5.8\,H_2O$	11.5
FeS	0.9
$2\,Fe_2O_3.3H_2O$	13.9
H_2O	3.9
	100.0

Compounds of iron compose 79 per cent. of the scale and the distribution of elemental iron in these is: as carbonate, 65; phosphate, 10; sulphide, 1.5; oxide (ferric), 23.5 per cent. The corroding agent has thus been water, rich in carbonic acid (and calcium bicarbonate) and containing also atmospheric oxygen and soluble sulphates. Bones have supplied the phosphoric acid and the organic matter associated with them has helped in the reduction of sulphate and probably augmented the sulphide by their decomposition.

APPENDIX.

Paraffin Wax. Two seal boxes from Corbridge were found to contain wax, in addition to the ordinary corrosion-products of the bronze, infiltrated calcium carbonate and mud. They were extracted with chloroform, the solvent evaporated and the oily residue recrystallised from boiling alcohol. In this way was obtained a soft, snow-white substance, m.p. 53°C. which was, chemically speaking, saturated. Analysis and molecular weight determination by micro-chemical methods, kindly provided by Prof. G. R. Clemo, gave the following results:

	1	2
C.	84.78	84.32
H.	14.35	14.47
	99.13	98.79

Mol. wt. 393, 378, 421, mean 406.

The material is thus a paraffin wax of the approximate formula $C_{30}H_{62}$. It may be surmised that it is of local origin, since oily exudations, containing solid paraffins, are of frequent occurrence in coal pits and have been described under various names, such as ozokerite, urpethite, middletonite.[31] It may be remarked that mediæval wax-seals are quite different in composition, being made of beeswax, sometimes mixed with colophony.[32]

Ornamental Stones. Mention may be made of the use of haematite as an ornamental stone in bronze harness trappings. In one case, however, the streak of the mineral was rather that of goethite than haematite. Both forms were encrusted with a wart-like mass of rust. On cleaning, they took an excellent polish and were quite effective as ornaments, though their softness must have proved a disadvantage in use.

Most ornamental stones, e.g. in signet rings and brooches, are artificial—enamels of various colours, dark green, purple, red and white, sometimes as many as three coloured strata being encountered in a single specimen. The enamel is quite glassy and often shows an abundance of gas-bubbles.

DESCRIPTION OF THE MICROGRAPHS.

The numbers in square brackets refer to the analyses in Table I.

PLATE I.

1. Housesteads. Ring × 120. Cu, 59.5; Sn, 1.0; Pb, 2.0; Zn, 36.0 [2]. The structure is that of a cast 60/40 brass. Secondary copper (dark) on the *beta*-constituent in lower part of the photograph. There is some doubt as to this alloy being Roman (v. text).

2. Benwell. Small cake x 120. Cu, 64.1; Sn, 33.0; Pb, 3.3; Zn, 0.3 [4]. Cast speculum metal. Dark corrosion-products fringe the *delta*-constituent in lower part of the photograph.
3. Housesteads. Ornament x 60. Cast *alpha*-bronze, not leaded.
4. Benwell. Ornament x 120. Cu, 77.4; Sn, 7.7; Pb, 14.0; Zn, 0.2. [10]. Cast bronze heavily leaded. Shows small amount of eutectoid with large blobs of lead one of which (bottom right) has been partly plucked out on grinding and discloses the bronze beneath.

PLATE 2

5. Benwell. Plummet x 90. Cu, 75.4; Sn, 7.9; Pb, 9.0; Zn, 7.1. [7]. Cast leaded bronze rich in zinc. Shows much eutectoid. but little lead.
6. Corbridge. Ornament x 120. Cu, 79.9; Sn, 6.0; Pb, 5.9; Zn, 6.7. [11] as in 5. Shows much eutectoid, somewhat clearer than the eutectoid in the straight bronzes.
7. Housesteads. Split ring x 120. *Alpha*-brass, cold-worked and annealed, still showing the relics of coring in the alternate light and dark bands.
8. Housesteads. Wire spiral x 45. Wrought *alpha*-bronze showing the dragging-out of the cores and non-metallic inclusions. parallel to the length of the wire.

PLATE 3.

9. Chesterholm. Split ring x 45. Wrought *alpha*-bronze, cores drawn out in parallel bands; metal finely recrystallised.
10. Housesteads. Unidentified x 120. Inclusion of cold-worked and annealed *alpha*-brass, with non-metallic constituents in parallel lines, in cast *alpha*-bronze. Imperfect weld.
11. Corbridge. Base of stag's head ornament x 120. Inclusion of wrought and fully annealed *alpha*-bronze in cast bronze, extremely rich in tin. The weld is perfect.
12. Corbridge. x 45. Rivet of wrought *alpha*-bronze (lower part) in head of fibula of cast *alpha*-bronze. Junction greatly corroded.

PLATE 4.

13. Corbridge. Rod of squarish section x 45. Cu, 74.8; Sn, 12.2; Pb, 7.0; Zn, 2.7, (O, 3.3). [6] Unetched. Excessive corrosion revealing casting structure. Some lead in round patches, some between the dendritic arms. In the latter case it cannot be distinguished from the corrosion-products.
14. Chesterholm. Staple for ring-hook x 45. Unetched. Very little lead. Corrosion of tin-rich constituent shows up the casting structure of the bronze.
15. Housesteads. Ornament x 90. Structure of 50/50 copper-silver alloy. Dark etching dendrites of copper-rich solid solution in eutectoid, the copper-rich constituent of which has been leached out.

16. Chesterholm. Nail × 90. Pure ferrite structure with Neumann's lines (distortion effect). Few small spots of cinder.

PLATE 5.

17. Corbridge. Thin plate × 120. Cu, 66.4; Sn, 22.6; Pb, 9.8; Zn, 0.2. [5]. Lead in large round blobs; the angular dark-etching material is the *delta* solid solution. The structure resembles that of cast 80/20 bronze. Has been used for ornamental purposes.
18. Benwell. Bowl × 120. Cu, 82.1; Sn, 9.6; Pb, 6.8; Zn, 1.6. [14]. Cast bronze with fair amount of eutectoid and lead.

PLATE 6.

19. Corbridge. Roundish wire, ornamental (Bracelet?) × 120. Cu, 94.9; Sn, 4.7. [26]. *Alpha*-bronze cold-worked and slightly annealed. Dark cores of original cast metal drawn out and broken into lenticular masses. Some slight recrystallisation visible in the lighter areas.
20. Corbridge. Flat ornamented disc × 90. Cold-worked and annealed *alpha*-bronze. Recrystallisation fairly complete, but original coring almost undisturbed.

PLATE 7.

21. As in 20, but at higher magnification (× 120) and etched to bring up the crystalline structure (with twinning) of the metal.
22. Housesteads. Tweezers × 120. Cold worked and slightly annealed. The cores are distorted and rudimentary recrystallisation is restricted to areas defined by the coring.

REFERENCES.

[1] They are dismissed by Haverfield with the words: "Of bronze much was found, but most of it was sadly perished." *See* Corstopitum. Report on the Excavations in 1909. *Arch. Ael.* 1910, 3rd Series, Vol. VI, p. 69.

[2] It may be noted that the mean total of 15 ancient bronzes analysed by Brazener is very close to this, viz. 98.6 per cent. *See* The Bucheum, 1934. Sir Robert Mond and Oliver H. Myers. Chap. XII. Metal Objects by C. O. Bannister, W. F. Brazener and Miss K. Schlesinger.

[3] It was observed by W. Flight, Journ. Chem. Soc. 1882. **41.** 134. that silver in ancient coins is usually accompanied by silver chloride.

[4] For information on this subject, see reports by C. H. Desch on Sumerian Copper. Brit. Ass. Reports 1928, 1929, 1930, 1931, 1933. Also Desch, Newcomen Soc. Trans 1933, 4, XIV, 95.

[5] It must be emphasised here that this grouping of bronzes and brasses is arbitrary. Even in modern practice the terms are used loosely.

[6] C. T. Mathewson, Amer. Journ. Sci. 1915. **40.** 525.

[7] Ancient Egyptian Materials and Industries. A Lucas, 1934, 2nd. Edition.

[8] C. T. Mathewson, *op cit.* Also C. F. Elam. Journ. Inst. Metals, 1932. **48.** 97.

[9] A. H. Church, Journ. Chem. Soc. 1865, 215 has analysed two Romano-British brasses containing 13.0 and 14.7 per cent. of zinc.

[10] The highest zinc-content of a Roman alloy found by Gowland is 27.7 per cent. Journ. Inst. Metals, 1912. **7.** 23.

[11] In this connexion it may be mentioned that Mudge, a century and a half ago, determined that the alloy containing 32 per cent. of tin was the hardest, but the one with 31.2 per cent. was most suitable for making mirrors, especially after re-melting to remove gas-bubbles. J. Mudge, Phil. Trans. Roy. Soc. 1777. 67. Part I, p. 296.

[12] Two similar highly-leaded bronzes, containing 23.5 and 24.3 per cent. of lead are mentioned in The Bucheum, and Phillips found 29.3 per cent. of lead in a Roman bronze.

[13] For an excellent and detailed account of the inferences to be drawn from the micro-structure of these alloys the reader is referred to C. T. Mathewson's paper, already cited, on ancient Peruvian bronzes from Macchu Picchu.

[14] See, for example, Ancient Egyptian Metallurgy. H. Garland; C. O. Bannister, 1927, p. 14.

[15] Sir H. C. H. Carpenter. Nature, 1932. **130.** 625.

[16] C. T. Mathewson, *op. cit.*

[17] Pliny (xxxiv. 97) mentions the making of a statuary metal from two parts of virgin copper (or brass) and one part of statuary scrap, the latter added, however, with the object of imparting the mellowness of age to the mixture.

[18] C. O. Bannister, J. A. Newcombe. Nature, 1925. **116.** 786.

[19] C. D. Bengough, R. M. Jones, R. Pirret. Journ. Inst, Metals, 1920. **23.** 65. W. H. Vernon, L. Whitley. *Ibid.* 1929. **42.** 181. 1930. **44.** 389.

[20] R. J. Gettens. Journ. Inst. Metals. Abs. 1933. 307.

[21] B. Lean, W. H. Watmough. Journ. Chem. Soc. 1898. 73. 148.

[22] In the corrosion of 80/20 copper-nickel alloy, it was found that the nickel was almost entirely leached out, the ratio of copper to nickel in the corrosion-product being 54 to 1. J. C. Hudson. Journ. Inst. Metals. 1929. **42.** 200, 409.

[23] Vivianite is common among the Roman remains. Peat from the excavation of the Benwell crossing soon became spotted, on exposure to air, with the blue mineral and it was found to be rich in ferrous phosphate. Iron objects from the Chesterholm well showed a similar behaviour. The phosphoric acid is derived from the associated bones.

[24] Mr. Brynmor Thomas has kindly supplied me with many of his analysis of soils from the North of England. In these, chlorine is very variable, ranging from 0.0006 to 0.0355 per cent.

[25] Ancient Egyptian Metallurgy, p. 165.

[26] For the use of gold-amalgam for the purpose of gilding, see Pliny. Nat. Hist. xxxiii. 61.

[27] Pliny (xxxiv. 143 to 146) has many interesting things to say of iron. When extolling the iron of Seres he states: " No other kind is made of sheer steel, (la mera acie) for the rest contain an admixture of iron of a softer character " (Bailey's translation).

[28] Described in detail by C. E. Pearson and the author in these Proceedings, 1934. ix. Part 3. 141. The only other description of iron from the Roman Wall is that of the Corbridge bloom v. Sir H. Bell. Journ. Iron and Steel Inst. 1927. 116. 203.

[29] In the extensive literature on the rusting of iron, there is frequent mention of the iron being partly in the ferrous condition. See,e.g. Dunstan, Jowett and Goulding. Journ. Chem. Soc. 1905. **87**. 1564; Moody. *Ibid.* 1906. **89**. 726; R. Stumper, Chemie et Industrie, 1925. **113**. 906.

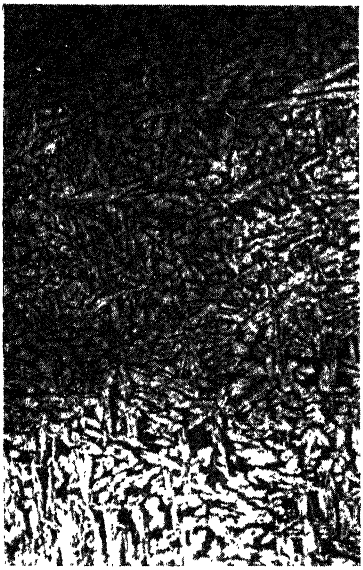
[30] In the 1909 Report on the Excavations at Corstopitum (op. cit. p. 66) mention is made by H. Louis of a mass of rusted material, assumed to be chain mail. This material lost 20 per cent. on ignition and the ignited residue contained: insoluble matter, 8; iron, 61; phosphorus, 0.86 per cent. Note is made of the fact that much of the iron was in the ferrous condition and that, owing to the large amount present, the phosphorus could not have come from the iron.

[31] Pliny (xxxv) uses the term bitumen for natural hydrocarbon mixtures, both liquid and solid. It is interesting to note his statement that such (liquid) mixtures can be thickened—presumably by distillation or evaporaton of the more volatile constituents.

For a list of local occurrences of hydrocarbons, see note by the author, the Vasculum, 1927. **13**. 41.

[32] T. T. Dobbie, J. J. Fox. Journ. Chem. Soc. 1914. 105. 705

PLATE 1.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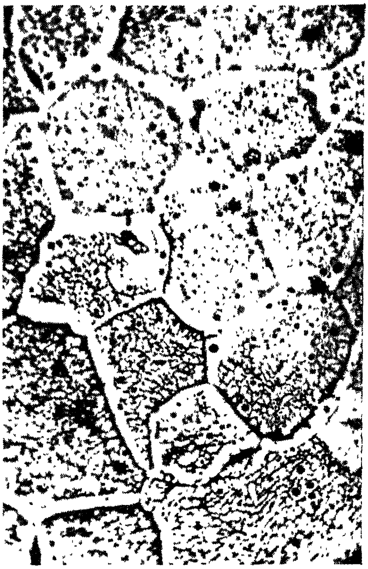
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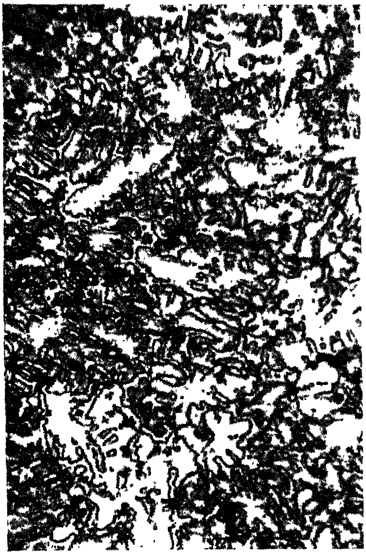
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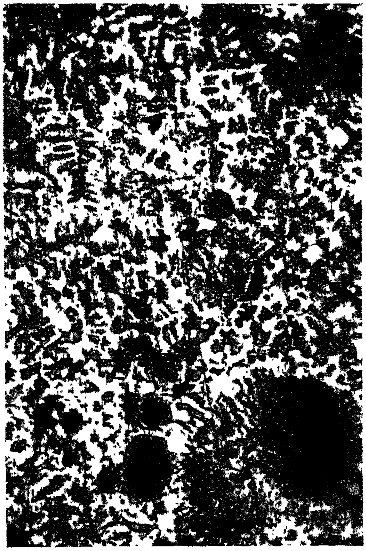
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PLATE 2.

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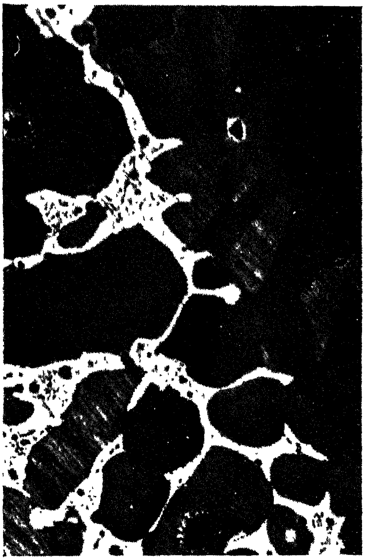

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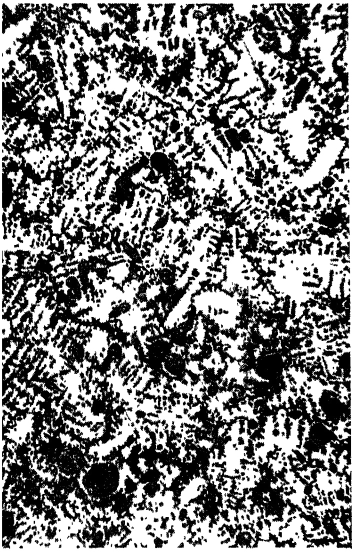

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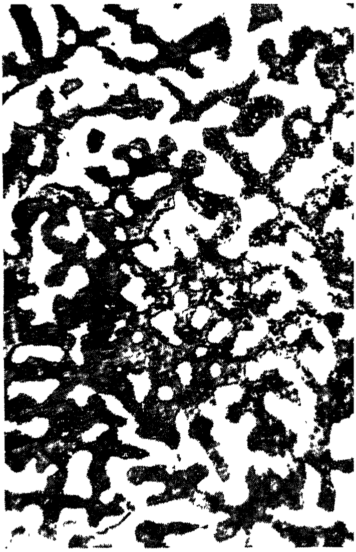

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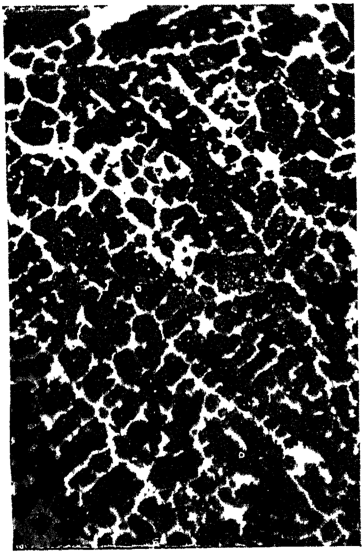

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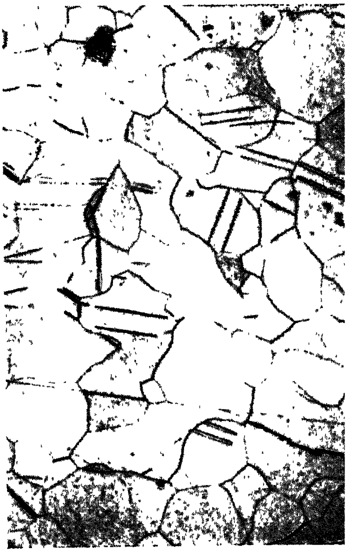

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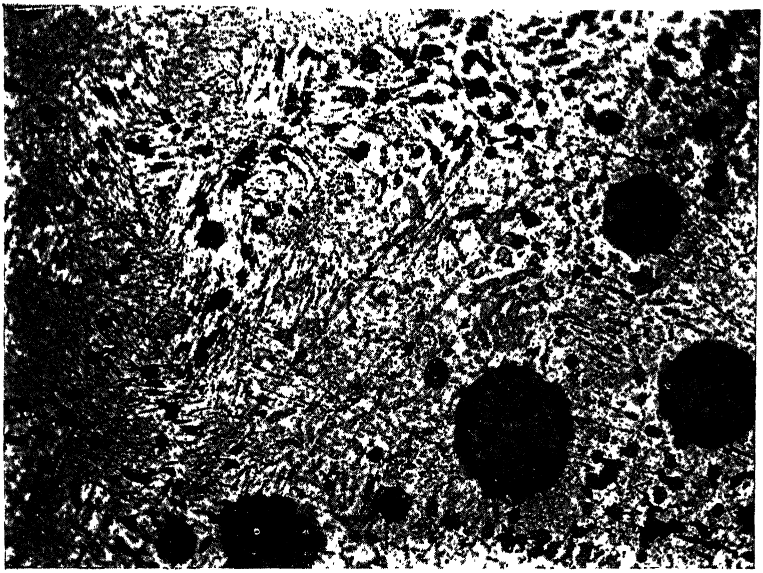

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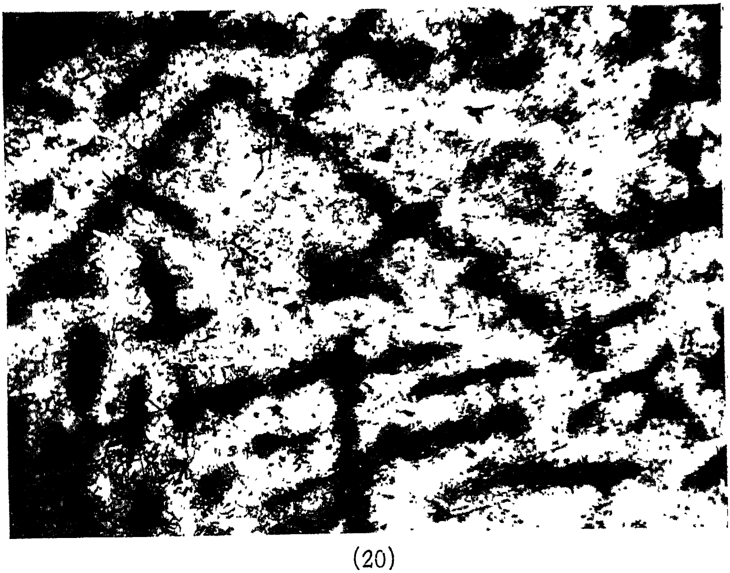

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PLATE 7.

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